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IRON

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HISTORY, PROPERTIES, & PROCESSES OF MANUFACTURE

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HISTORY, PROPERTIES, & PROCESSES OF MANUFACTURE

BY

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PREFACE TO THE FIRST EDITION.

DURING the publication of the eighth edition of the "Encyclopædia Britannica," I was suddenly called upon to write an article on the Manufacture of Iron; and it was intimated to me that the publication was so far advanced that I could not be allowed more than a few weeks for its completion. Thus placed, with other professional engagements to attend to, I had not only to work early and late, but I had to hurry through the work, in order to prevent delay and disappointment in the appearance of the volume. It was under these conditions the article was written, and they must be my apology for the imperfections it contains.

The Publishers, aware of these circumstances, have very handsomely come forward with an offer to print the article in a more complete state, in a separate volume; and having made considerable additions, I again submit it in a form which, I trust, may be more useful than when it appeared in the publication in question.

A very slight acquaintance with natural science will exhibit the wisdom of a bountiful Creator in the wide diffusion and abundant supply of iron and coal, two of the greatest boons conferred upon the human race. If we refer to the history of the past, and trace the change from barbarism to a state of intellectual culture, we see at every step the contrivances and appliances of the "cunning workers in iron." These have always been the associates of mental progress, and the forerunners of supply to the wants and necessities of our social existence.

In this treatise I have endeavoured, in a concise form, to trace the progress of the Iron Manufacture from its earliest beginnings down to the present time, and the various improvements which have been effected in the reduction of the ores, and the subsequent manipulation of the crude iron. I have also given analyses of the ores and fuel, so far as they bear on the results of the different processes of manufacture; and from this the reader will see how much we owe to chemical science, and to the distinguished men who have laboured so industriously and successfully in that important field of research.

The description of the furnaces, machinery, etc., employed in the production of iron, I have, from my own

experience, been enabled to trace from its almost primitive condition to its present high state of improvement. There is still much to be done; and now that the subject of reduction, conversion, rolling, forging, etc., is so well understood, we may reasonably look forward to much greater improvements, combined probably with more extended chemical researches, calculated to establish a new era in the history of the manufacture of iron and steel.

In connection with the history of iron and its manufacture, I might have treated as a question of equal importance, Iron Appliances; a subject of great magnitude and such as to require a distinct treatise. I have only partially treated of it in this publication, and any further notice of it in this place would only disappoint the reader by its incompleteness.

On the subject of statistics, I am fortunate in having before me the returns of Mr. Robert Hunt, F.R.S., of the School of Mines, published in the "Memoirs of the Geological Survey of Great Britain." To Mr. Bessemer I owe the very complete and interesting details of the process he has introduced, along with accurate drawings of the best forms of apparatus, embodying the results of his laborious and important investigations down to the most recent date. To Mr. Mushet, Mr.

Frith, and Mr. Clay, I am also indebted for information regarding the most recent improvements and discoveries effected in different processes; and to my own secretary, Mr. Unwin, for the able assistance I always receive from him in the execution and progress of researches in practical science.

PREFACE TO THE SECOND EDITION.

THE great improvements which of late years have taken place in the manufacture of iron and steel are of such a character as not only to justify a new edition of this work, but to elaborate more in detail the different processes that have been introduced since it was first written. The magnitude and importance of the changes now in progress are calculated to establish a new era in the history of the manufacture—from the smelting of the ore to the conversion of the crude metal into malleable iron or steel. Chemical discoveries and mechanical manipulations go together hand in hand in these improvements, and we may safely predict that a state of transition calculated to establish a total revolution in this manufacture is not far distant. The ordinary process of decarbonisation in the refinery and the puddling furnace, appears to yield to the more important system of boiling recently introduced for the manufacture of steel and homogeneous iron, and assuming this to be done by puddling or the Bessemer

process, at a moderate cost, it then follows that steel of much greater value, answering all the purposes of ductile iron, and of nearly double tenacity, will be produced.

Anticipating these results, I have given, through the medium of Mr. Bessemer, an elaborate description of the process by which these objects are attained, and I have also noticed other improvements that have been effected in the steel and puddling process; and these, with extracts from Dr. Percy's valuable work on Metallurgy, exhibits the present improved state of our knowledge in this highly valuable and important branch of industry.

April 27, 1865.

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INTRODUCTION.

IRON, on account of its abundance, working qualities, and tenacity, is probably the most useful and valuable of metals. According to Dr. Ure, "it is capable of being cast into moulds of any form, of being drawn into wire of any desired length or fineness, of being extended into plates or sheets, of being bent in every direction, of being sharpened, or hardened, or softened at pleasure. Iron accommodates itself to all our wants and desires, and even to our caprices; it is equally serviceable to the arts, the sciences, to agriculture, and war; the same ore furnishes the sword, the ploughshare, the scythe, the pruning-hook, the needle, the graver, the spring of a watch or of a carriage, the chisel, the chain, the anchor, the compass, the cannon, and the bomb. It is a medicine of much virtue, and the only metal friendly to the human frame." In its primitive position, it is commingled with the earth's strata in bountiful profusion; it is found in various combinations and conditions in every formation; and it is a constituent element of both animals and vegetables.

In treating of the manufacture, properties, and production of this most important material, it will conduce to perspicuity to arrange the subject under twelve distinct heads, viz.—

I. The History; II. The Ores; III. The Fuel; IV. Smelting by the Hot and Cold Blast; V. Manufacture of Wrought-Iron; VI. The Mechanical Operations of the Cast-Iron Manufacture; VII. The Forge; VIII. Mr. Bessemer's Process; IX. The Manufacture of Steel; X. The Mechanical Properties of Cast and Wrought Iron and Steel; XI. Armour-Plates; XII. The Chemical Constituents of Iron in its Manufactured States; XIII. Statistics of the Iron Trade.

CHAPTER I.

THE HISTORY OF THE IRON MANUFACTURE.

MALLEABLE iron appears to have been known from a remote antiquity. Its obvious utility and great superiority over the softer metals, then commonly used, combined with the expense of its reduction, caused it to be highly prized, though the extreme difficulty of working it by the rude methods then employed greatly restricted its application.* There are notices in Homer and Hesiod of the arts of reducing and forging iron, but cast-iron was then unknown, an imperfectly malleable iron being produced at once from the ores in the furnace. It is probable that the Greeks obtained most of their iron through the Phœnicians from the shores of the Black Sea and from Laconia.

It would be interesting to trace the gradual advances which have been made in the reduction of iron from its discovery to the present time; to inquire into the circumstances which led to the successive changes in the processes, and into the principle on which those changes were founded; to examine into the differences in the products which from time to time ensued, and to notice the influence of these conditions on the extent and progress of the manufacture. Our knowledge of these changes, however, is scanty and imperfect, and we can only conjecture what was probably its early progress.

* This is shown by the epithet πολύκμητος (much-wrought), applied to it by Homer (*Iliad*, vi. 48).

On this interesting topic Dr. Percy, in his recently published "Metallurgy of Iron and Steel," observes,—"That the question, whether the early Egyptians were acquainted with iron, and employed steel in sculpturing their monuments, has given rise to much discussion. The subject has recently been considered by Mr. A. Henry Rhind, who conceives that, as 'between the epoch of the Homeric poems and the full historic period of Greece, iron had come to be extensively employed there,' so, 'in like manner, and within about the the same interval—if probably with an earlier commencement —the same metal was more or less completely displacing bronze in Egypt.' In the tomb of Sebau which he explored, and which he assigns reasons for believing had not been opened for nearly 2000 years previously, he discovered on the massive doors of the inner repositories hasps and nails 'still as lustrous and as pliant as on the day they left the forge.'

"That the Assyrians were well acquainted with iron is clearly established by the explorations of Mr. Layard, who has enriched the collection of the British Museum with many objects of iron from Nineveh of the highest interest. Amongst these may be particularly specified tools employed for the most ordinary purposes, such as picks, hammers, knives, and saws. There is a saw similar in construction to that now used by carpenters for sawing large pieces of timber across. It has been described and figured by Mr. Layard. It consists of a blade 3 feet 8 inches long and 4⅝ inches broad throughout its entire length, except at one end, where it is narrowed, and was, no doubt, let into a handle of wood, the rivets being visible upon it. The other end was probably similar, but, unfortunately, it has been broken off. The metal seems to be almost wholly converted into oxide, yet sufficient remains strongly to attract the magnetic needle; that is, supposing no magnetic oxide of iron to be present. There is no evidence

to show whether it originally consisted of iron or steel, though this point might possibly be ascertained by a very careful chemical investigation. As an illustration of ancient metallurgy, there is no object in the museum of greater interest than this rusted saw, which has only recently been exposed to public view. It was found in the North-West Palace at Nimroud; and it is computed that, while it could not be later in date than 880 B.C., it may have been considerably earlier. The fact of iron having been applied to common hammer-heads, for which bronze might have proved a tolerably good substitute, indicates that iron was certainly as cheap, if not cheaper in those days, than bronze; and the correctness of this inference is strikingly confirmed by many other objects from the same locality, consisting of cores of iron around which bronze has been cast.

"Other Assyrian antiquities of iron, which deserve particular attention, are portions of chain armour and two helmets ornamented with bronze. These helmets are greatly corroded by rust, but they are sufficiently perfect in form to indicate excellency in the quality of the iron, and no ordinary skill in working the metal.

"The early history of the art of extracting and working iron in this kingdom still remains obscure. However probable it may be, it is not yet certain, that the Britons were acquainted with the use of iron and the mode of reducing its ores anterior to the invasion of Cæsar. Mr. Lower, however, observes that it is not improbable that the iron of Sussex was wrought in times even anterior to the conquest of this island by the Romans. Previously to the advent of Cæsar, the inhabitants of Britain must have made a considerable advance in the arts of civilization. To have subjugated the horse, and to have made such proficiency in many of the details of military science, as the conqueror of Gaul found to his cost that they possessed, may well assert for them a degree of refinement

quite at variance with the too generally received opinion that they were mere savages and barbarians. If the use of iron be taken as the point at which pure barbarism ends and civilization begins, the ancient Britons had certainly passed that point, as the formidable scythes attached to the axles of their chariots sufficiently prove, to say nothing of the chariots themselves, which obviously were not made without the use of iron tools."

The furnaces which were first employed for smelting iron were probably similar to those now called *air-bloomeries.* They were probably simple conical structures, with small openings below for the admission of air, and a large one above for the escape of the products of combustion, and would be erected on high grounds in order that the wind might assist combustion. The fire being kindled, successive layers of ore and charcoal would be placed in it, and the heat regulated by opening or closing the apertures below.

The process of reduction would consist of the deoxidation of the ore and the cementation of the metal by long-continued heat. The temperature would never rise sufficiently high to fuse the ore, and the product would therefore be an imperfectly malleable iron, mixed with scoriæ and unreduced oxide. It would then be brought under the hammer, and fashioned into a rude bloom, during which process it would be freed from the greater portion of its earthy impurities.

By such a process as this the Romans probably worked the iron ores of our own island; scoriæ, the refuse of ancient bloomeries, occur in various localities, in some cases identified with that people by the coincident remains of altars dedicated to the god who presided over iron. Mungo Park saw a rude furnace of this kind used by the Africans, and, indeed with some modifications, it is still retained in Spain, along the coasts of the Mediterranean, and in some parts of America, where rich specular or magnetic ores are worked.

The advantages of an artificial blast would soon become manifest, and a pair of bellows, or a cylinder and piston, would soon be applied to the simple construction mentioned above. Homer represents Hephæstus as throwing the materials from which the shield of Achilles was to be forged into a furnace urged by twenty pairs of bellows (φῦσαι). The inhabitants of Madagascar smelt iron in much the same way, their blowing apparatus, however, consisting of hollow trunks of trees, with loosely-fitting pistons worked by hand.

The furnace corresponds to the *blast*-bloomery, and has by successive improvements developed into the blast-furnace, now almost universally used, and into the *Catalan forge*, still employed in some districts. The application of the blast would offer considerable advantages; it would obviate the necessity of an elevated site, place the temperature more immediately under the direction of the smelter, and render the whole process more regular and certain. The method of reduction remained the same as before, but the product would differ considerably, for whenever the blast was sufficiently powerful, the iron would be *fused*, a partial carburation would take place, and the resulting metal would be a species of steel utterly useless to the workmen of those days; hence, it seems necessary to infer, that a rude process of refining was invented: the metal being again heated with charcoal, and the blast directed over its surface, the carbon would be burned out, and the iron become tough and malleable. The processes might perhaps form two successive stages of one operation, as at present practised with the Catalan forge.

The increasing demand for iron, and the progress of internal communication, would lead the smelter to increase the size and height of his bloomery, and this probably would lead to a very unexpected result. The greater length through which the ore had to descend would prolong its contact with the charcoal, and a higher state of carburation would ensue,

the product being cast-iron—a compound till then perhaps unknown.

From the time that cast-iron became the product of the smelting-furnace, the refining would be made a separate process, requiring a separate furnace and machinery. It would soon be found also, that, as the furnace increased in height, the pressure of the superincumbent mass would render the materials so dense as to retard the ascent of the blast, and thus cause it to become soft and inefficient; hence the internal buttresses called *boshes* were first introduced to support the weight of the charge, relieving the central parts from the pressure, and permitting the free ascent of the blast. Whilst the good quality of the iron and the regularity of the process were thus ensured, increase of quantity was the result of improvements in the blowing apparatus, which was now enlarged and worked by water-power. With these modifications, the furnace was the same essentially as the blast-furnace now employed, though not so large; indeed, until the introduction of coke, at a much later period, the blast-furnace seldom exceeded 15 feet in height by 6 at the widest diameter. The more perfect operation of the blast-furnace allowed the reduction of the heaps of scoriæ, which had been gradually accumulating during the period that the blast-bloomeries had been in operation, and which contained 30 to 40 per cent of iron. A new species of property was thus created—extensive proprietorships of Danish and Roman cinders were formed. Large deposits of scoriæ, which for ages had lain concealed beneath forests of decayed oak, were dug up; and in Dean Forest it is computed that twenty furnaces, for a period of upwards of 300 years, were supplied chiefly with the bloomery cinders as a substitute for iron ore.

The exact date of the discovery of cast-iron has not been satisfactorily determined. According to the antiquarian Lower, Dr. Percy states, that the first cannons of cast-iron were

manufactured at Buckstead (Bucksteed), in Sussex, by Ralph Hoge or Hogge, in 1543 (35 Henry VIII). "This founder," it is stated, "employed as his assistant Peter Baude, a Frenchman, whom he had probably brought over to teach him the improved method." But, as Lower remarks, this connection was not of long continuance; for it is recorded that "John Johnson, covenant servant to the said P. Bawd (*sic*), succeeded and exceeded his master in this his art of casting ordnance, making them cleaner and to better perfection. And his son, Thomas Johnson, a special workman, in and before the year 1595 made 42 cast pieces of great ordnance of iron, for the Earl of Cumberland, weighing 6000 lbs., or three tons apiece." However, it is not certain whether Sussex was the scene of these operations.

Agricola, who was born in 1494 and died in 1555, appears to have been acquainted with cast-iron; for he thus writes: "Iron, smelted from iron-stone, is easily fusible, and can be tapped off. When the same, after the slag has been lifted off, is further heated to redness (*glüht*, which the German translator renders 'frischt'), it becomes malleable, and may be worked under the hammer and drawn out, but can no longer be easily poured, except when it is again melted down." The last part of the sentence is somewhat obscure.

At what period the complete transformation of the blast-bloomery into the blast-furnace was effected, it is impossible to say. It was probably in the early part of the sixteenth century, as we find that in the seventeenth the art of casting had arrived at a considerable degree of perfection, and in the reign of Elizabeth there was a considerable export trade of cast-iron ordnance to the Continent. In the forest of Dean are the remains of two blast-furnaces which formerly belonged to the kings of England; but they have been out of blast since the commencement of the struggle between Charles I. and his Parliament. Calculating from the quantity of scoriæ

accumulated in their immediate neighbourhood, which appears to have lain undisturbed for the last two centuries, Mr. Mushet has attempted to deduce the period of their erection, which he conceives to have been about the year 1550, in the time of Edward VI.

Up to this period wood charcoal was the only material employed in smelting operations; but the wants of a constantly increasing population, not less than the great consumption of the blast-furnaces themselves, created a scarcity of this essential material, and gave a check to the manufacture. To such an extent had the wood been destroyed, that the cutting down of timber for the use of the ironworks was prohibited by special enactments; and the forests of Sussex alone appear to have been exempt from the general decree of conservation. The number of furnaces in blast decreased three-fourths, and the annual production, which but a short time before is said to have been 180,000 tons, was in 1740 reduced to only 17,350 tons.

James I. granted patents to ironmasters in various parts of the kingdom for using pit-coal in the manufacture of iron. The obstacles to its introduction, however, were numerous, and not easily overcome. Lord Dudley appears to have been the first successful patentee connected with the iron manufacture; and his patent, obtained in 1621, related to "the misterie and arte of melting iron ewre, and of making the same into cast workes or barrs, with sea coles or pit coles in furnaces, with bellowes." Lord Dudley was only able to make iron at the rate of three tons a week; but so important did his patent appear, that it was specially exempted from the operation of James I.'s statute abolishing the grants of monopolies. The comparatively incombustible nature of coke, and its feebler chemical affinities, rendered a more powerful blast and a longer subjection to the heat indispensable to its successful adoption. Ignorance of the causes of failure operated long

and seriously, but all difficulties were at length surmounted. An enlargement of the height of the furnace prolonged the contact of the ore and coke, and at last the employment of the steam-engine and improved blowing apparatus rendered the blast much more powerful and regular, and gave that impetus to the manufacture which has caused Great Britain to take the first rank in this branch of industry.

The following extract from Dr. Percy's work, "Metallurgy of Iron and Steel," gives a graphic description, by Mrs. Darby, of the progress made by that family in the manufacture of iron.

"About the year 1676, John Darby, a malt-maker residing at Bristol, sailed to Holland, and engaged Dutch brassfounders to return with him to England. In 1706, in conjunction with four partners, he established at Bristol the brass-works known as Baptist Mills, of which he took the management. He conceived the idea that cast-iron might be substituted for brass, and prevailed upon his Dutch workmen to try to make iron castings in moulds of sand; but they failed, and considerable loss was incurred in their experiments.

"At this time a Welsh shepherd-boy, named John Thomas, succeeded in rescuing a flock of his master's sheep from a snow drift; and later in the spring of the same year, during heavy rain and the melting of the snow, he swam a river to fetch home a herd of mountain cattle. These he collected and drove to the river, but the ford had now become a boiling torrent. He nevertheless crossed it on the back of an ox, and brought home the whole herd in safety. As a reward for his courage, his master presented him with four of the sheep which he had saved. He sold their wool in order to buy better clothing for himself, and afterwards disposed of the sheep, so that he might obtain money wherewith to travel to Bristol and 'seek his fortune.' Afraid of being pressed for a soldier if found in Bristol out of place, as it was then the

time of the Duke of Marlborough's wars, he requested his master to recommend him as an apprentice to a relative, who was one of the partners of the Baptist Mills. The boy was accordingly sent into the brass-works, until he should procure employment. As he was looking on during the trials of the Dutch workmen to cast iron, he said to Abraham Darby that he 'thought he saw how they had missed it.' He begged to be allowed to try, and he and Abraham Darby remained alone in the workshop the same night for the purpose. Before morning they had cast an iron pot. The boy Thomas entered into an agreement to serve Abraham Darby and keep the secret. He was enticed by the offer of double wages to leave his master; but he continued nobly faithful, and afterwards showed his fidelity to his master's widow and children in their evil days. From 1709 to 1828 the family of Thomas were confidential and much valued agents to the descendants of Abraham Darby. For more than 100 years after the night in which Thomas and his master made their successful experiment of producing an iron casting in a mould of fine sand, with its two wooden frames and its air-holes, the same process was practised and kept secret at Colebrook Dale, with plugged key-holes and barred doors.

"The sleeping partners at Baptist Mills became dissatisfied with Darby, believing that he had lost his judgment, and was wasting money in fruitless experiments. The partnership was consequently dissolved, and Darby drew out his share of the capital. He took a lease of the furnace at Colebrook Dale, and removed with his family to Madeley Court in 1709, John Thomas accompanying him.

"While Abraham Darby lived, affairs prospered; but, unhappily, after his death, a brother-in-law in whom he had confided, acted dishonestly towards the widow and family, and even defrauded some of the workmen.

"Young Abraham Darby entered upon the management

of the Colebrook Dale Ironworks about 1730. As the supply of charcoal was fast failing, Abraham Darby attempted to smelt with a mixture of raw coal and charcoal, but did not succeed. Between 1730 and 1735 he determined to treat pit-coal as his charcoal-burners treated wood. He built a fire-proof hearth in the open air, piled upon it a circular mound of coal, and covered it with clay and cinders, leaving access to just sufficient air to maintain slow combustion. Having thus made a good stock of coke, he proceeded to experiment upon it as a substitute for charcoal. He himself watched the filling of his furnace during six days and nights, having no regular sleep, and taking his meals at the furnace top. On the sixth evening, after many disappointments, the experiment succeeded, and the iron ran out well. He then fell asleep in the bridge house at the top of his old-fashioned furnace so soundly that his men could not wake him, and carried him sleeping to his house, a quarter of a mile distant. From that time his success was rapid. To increase the power of his water-wheels of 24 feet diameter, he set up a 'fire-engine' (*i.e.* an old atmospheric steam-engine), to raise water from under the lowest and send it to the upper pond, which supplied water to the works, and put in motion the largest bellows that had been made. He obtained additional leases of valuable minerals, and erected seven furnaces, with five fire-engines. In 1754 the first furnace at Horsehay was blown in. In December 1756, 'Horsehay's work' was declared to be 'at a top pinnacle of prosperity, 20 and 22 tons per week, and sold off as fast as made, at profit enough.' Iron rails were laid down for the tram waggons between Horsehay and Colebrook Dale about this time."

The first great improvement in the blowing apparatus was the substitution of large cylinders, with closely-fitting pistons, for the bellows. The earliest of any magnitude were probably those erected by Smeaton at the Carron Ironworks, in 1760.

In 1783-84, Mr. Cort of Gosport introduced the processes of puddling and rolling, two of the most important inventions connected with the production of iron since the employment of the blast-furnace.

Mr. Cort obtained two patents, the first in 1783, respecting "a peculiar method and process of preparing, welding, and working various sorts of iron, and of reducing the same into *uses* by machinery, and a furnace and other apparatus adapted to the same purpose." In February 1784 he obtained a second, comprising "shingling, welding, and manufacturing iron and steel into bars, plates, rods, and otherwise, of purer quality, in larger quantities, by a more effectual application of fires and machinery, and with a greater yield, than any method before put in practice." His first patent comprises methods of faggoting bars for various kinds of uses, the hammer and anvil being employed, and the faggots brought to a welding heat in a balling furnace instead of one with a blast. By passing faggots through rollers, "all the earthy particles are pressed out," and the iron compressed into a tough and fibrous state. Bars of bad quality may be improved by rolling, and several bars rolled together become perfectly united. He points out that iron plates may be made in the same manner. He shows how the shape and dimensions of the plates and bars may be determined by collars and grooves in the rollers. In this patent we see, therefore, he has developed his system of faggoting and heating scraps and bars, and welding them into a mass, and compressing them into form by means of rollers and hammers. And the introduction of rollers in this process was a step in discovery we owe to him. There was still wanting a process for the production in this country in large quantities of the wrought iron itself. This he provided in his second patent. He introduced a reverberatory furnace heated by coal, and with a concave bottom into which the fluid metal is run from the smelting furnace; and he showed how,

by a process of puddling, while exposed to the oxidising current of flame and air, the cast metal could be rendered malleable. He describes in his patent the stirring of the metal till ebullition ceases, and its collection as it becomes less fusible into blooms; the hammering of these to get rid of the slag, and their reduction to a marketable shape by the processes described in his previous patent. It would be a difficult task to enumerate all the services rendered by Mr. Cort to the iron industry of this country, or sufficiently to express our sympathy with the relatives and descendants of a man to whose mechanical inventions we owe so much of our national greatness. It is, perhaps, not generally known that Mr. Henry Cort expended a fortune of upwards of £20,000 in perfecting his inventions for puddling iron, and rolling it into bars and plates; that he was robbed of the fruit of his discoveries by the villany of officials in a high department of the Government, and that he was ultimately left to starve by the apathy and selfishness of an ungrateful country. When these facts are known, and it has been ascertained that Mr. Henry Cort's inventions have conferred an amount of wealth on the country equivalent to *six hundred millions sterling*, and have given employment to *six hundred thousand* of the working population of our land for the last three or four generations, we are surely justified in referring to services of such vast importance, and in advocating the principle that such substantial proofs of the nation's gratitude should be afforded to rescue from penury and want the descendants of such a benefactor.

About this time the steam-engine of James Watt came into use, and along with it commenced a new era in the history of the iron trade and every other branch of industry. Its immense power, economy, and convenience of application, brought it at once into general use. It was soon applied to pumping, blowing, and rolling; it enabled mines to be sunk to a greater depth; refractory ores to be reduced with facility;

and the processes of rolling, forging, etc., to be effected with a rapidity previously unknown in this or any other country.

Of late years, Scotland has made considerable progress in the iron manufacture. The introduction of railway communication, and the invention of the hot-blast, have given a stimulus to the trade which has raised Glasgow and its vicinity into importance as an iron district; and few towns possess greater facilities for the sale of their produce than this central depôt of the mineral treasures of the country by which it is surrounded.

The hot-blast process, for which a patent was taken out by Mr. Neilson in 1824, has effected an entire revolution in the iron industry of Great Britain, and forms the last era in the history of this material. This patent consists in the improved application of air to produce heat in forges and furnaces where bellows or other blowing apparatus are required. The blast produced in the ordinary way is heated in a closed air-vessel, before being conducted into the furnace, to a considerable temperature. The air-vessel was heated by a fire distinct from that to which the blast was applied. The manner, however, of heating the air-vessel is immaterial to the effect if it be kept at a proper temperature. This simple but effective invention has given such facilities for the reduction of refractory ores, that between three and four times the quantity of iron can be produced weekly, with an expenditure of little more than one-third of the fuel; and, moreover, the coal does not in most cases require to be coked, or the ores to be calcined.

The more important of the changes of the iron manufacture since Neilson's time have been, to sum them up very briefly, the direct production of wrought iron from rich ores in a reverberatory furnace, accomplished by Mr. Clay in 1840; the use of oxide of manganese in the production of steel, attempted by Reynolds in 1799, and by many others since, including Heath and Vickers in 1839, Schafhautl in 1835, Mr. Leachman

in 1853, Mr. Brooman in 1854, Mr. Crowley in 1855, and Mr. Mushet in 1856 ; in most cases other materials, as chloride of sodium, ferrocyanide of potassium, and carbonate of lime, in various proportions, being also employed.

The introduction of anthracite, stone-coal, or culm, in smelting, is due chiefly to Mr. Crane in 1836, and Mr. Budd in 1842, a blast of high pressure being employed, heated to a high temperature. The application of peat has also been attended with success, very good qualities of iron being produced with it on the Continent, and to a small extent in Ireland. Plans have also been introduced for the reduction, and for puddling iron, by the gaseous product of combustion alone, the ores not being allowed to come in contact with the mineral constituents of the fuel. In the case of the processes of puddling and refining, plans of this kind have for some time been in use in Silesia ; and more recently Dr. Gurlt has proposed the reduction of the metal in the same way. Mr. Nasmyth made one of the most important additions to the machinery of the iron trade by the invention of the steam-hammer in 1842 : this most powerful and ingenious tool has received of late many modifications in the hands of Mr. Condie, Mr. Naylor, Mr. Wilson, and others.

The utilisation of the waste or gaseous products was attempted by Teague in 1832, and Meckenheim in 1842, and has been the subject of many patents. Steam has been employed in puddling by Guest and Evans in 1840, Nasmyth in 1854, Martien and Bessemer in 1855, and Talabot in 1857. Messrs. Lea and Hunt would use the products of the coke furnace as a source of heat in puddling, and Mr. Meikle endeavoured to collect the gases and employ them in smelting. Captain Uchatius (1855) has successfully converted cast metal into steel by granulating it in water, and decarbonising it by fusion with spathose ore. Cyanogen has been used in the production of steel by cementation by Mr. Brooman and Mr.

Newton, and Mr. Bessemer has introduced an entirely new process for obtaining both wrought iron and steel by decarbonising it in a fluid state, by passing through it copious currents of air and steam. Other manufacturers are producing a homogeneous and malleable steel in the form of plates and bars by a modification of the puddling process.

In conclusion, we may add that there appear to have been five distinct epochs in the history of the iron trade.

The *first* dating from the employment of an artificial blast to accelerate combustion.

The *second* marked by the employment of coke for reduction, about the year 1750.

The *third* dating from the introduction of the steam-engine; and on account of the facilities which that invention has given for raising the ores, pumping the mines, supplying the furnace with a copious and regular blast, and moving the powerful forge and rolling machinery, we may safely attribute this era to the genius of James Watt.

The *fourth* epoch is indicated by the introduction of the system of puddling and rolling, very soon after the employment of the steam-engine.

The *fifth*, and last—though not the least important epoch in the history of this manufacture—is marked by the application of the hot-blast—an invention which has increased the production of iron fourfold, and has enabled the ironmaster to smelt otherwise useless and unreducible ores; it has abolished the processes of coking and roasting, and has given facilities for a large and rapid production, far beyond the most sanguine anticipations of its inventor. Manufacturers, taking advantage of so powerful an agent, have not hesitated to reduce improper materials, such as cinder-heaps and impure ores; and by unduly hastening the process, and attending to quantity more than to quality, have produced an inferior description of iron, that has brought the invention into unmerited obloquy.

CHAPTER II.

THE ORES.

THE ores of iron are found in profuse abundance in every latitude, embedded in or stratified with every formation. They occur both crystallized, massive, and arenaceous, lying deep in strata of vast extent, filling veins and faults in other rocks, and scattered over the surface of the ground. Sometimes, but rarely, found native; usually as oxides, sulphurets, or carbonates, more or less mingled with other substances. Of these ores there are perhaps twenty varieties, many of which are, however, rare; others are combined with substances which unfit them for the manufacture of iron, so that the remainder may be classed under the following general heads; their composition, however, varies greatly:—

1. The magnetic oxides, in which the iron occurs, as $Fe_3 O_4$ or $Fe_2 O_3 + Fe O$, containing 72·4 per cent of iron to 27.6 of oxygen, supposing it pure. This is the purest ore which is worked; the best Swedish metal is manufactured from it. It is found in primitive rocks, and is widely diffused over the globe. The beds of ore at Arendal, Täberg, Kurunavara, etc., consist of this oxide in a massive state.

2. Specular iron ore and red hæmatite, peroxide of iron, $Fe_2 O_3$, containing 70 per cent of iron to 30 of oxygen, when pure. This is a rich and valuable ore, and has been worked from a remote antiquity in Elba and Spain; it occurs in the caves of Etna and Vesuvius as lustrous specular iron. Red hæmatite occurs in botyroidal radiating masses in Cumber-

land, Saxony, Bohemia, and the Hartz, and in America abundantly.

3. Brown hæmatite, or hydrated peroxide of iron, 2 $Fe_2 O_3 + 3 HO$. Brown hæmatite occurs massive, mammillary, and stalactitic. Decomposed earthy varieties are known as ochrey brown iron ore. Brown and yellow clay ironstone is mingled oxide and clay. Bog ore is found in beds in Bohemia, Poland, and Russia, and usually contains phosphates.

4. Carbonate of iron, or spathic iron ore, $Fe O, CO_2$. This ore occurs mixed with large quantities of argillaceous, carbonaceous, and silicious substances, forming the large deposits of spathic iron ore, clay-ironstone, and blackbands, from which most of the iron of this country is obtained. These strata are generally found in close proximity to the Coal Measures. In Styria and Carinthia it forms extensive tracts in gneiss. The spathic ores, and also the silicious ores, are comparatively pure. The clay-ironstones, and still more the blackbands, are much poorer in iron.

5. In addition to the above, we may mention that native iron has been obtained in masses, usually of meteoric origin, in various parts of the world, and in this case contains from 1 to 20 per cent of nickel. At Yale College, in America, a meteorolite is preserved, weighing 1635 lbs.; length 3 feet 4 inches; breadth, 2 feet 4 inches; height, 1 foot 4 inches. It contained 90 to 93 per cent of iron, and 8·8 to 9·6 per cent of nickel. Pallas discovered a meteorolite in Siberia weighing 1600 lbs.; and still larger masses have been found in South America. At Canaan, Connecticut (*American Journal of Science*, xii. 154, and (2) v. 292), a mass, supposed to be of terrestrial origin, was found, in the form of a plate or vein two inches thick, attached to a mass of mica slate rock. Iron pyrites ($Fe S_2$) occurs abundantly in rocks of all ages, in cubes, nodules, and veins. It is used in the manufacture of sulphur, sulphuric acid, and sulphate of iron; but its composition

renders it unavailable for the production of iron itself. The arsenical, chromic, and titaniferous ores, and the borate, columbate, tungstate, phosphate, etc., of iron, do not need a more lengthened notice in this treatise.

All the above ores are more or less mixed with silica, alumina, oxide of manganese, etc.; and it may not be uninteresting to glance at their chemical composition and their geographical distribution in Europe and America.

England possesses peculiar and remarkable advantages for the manufacture of iron. The ores are found in exhaustless abundance, usually interstratified with the coal necessary for their reduction, and in close proximity to the Mountain Limestone, which is used as a flux. In few countries do these three essential materials occur in such abundance, or so near together as to give the necessary facilities for a large and profitable production.

In the North of England the ores of iron occur, geologically speaking, in the three formations known as the Carboniferous Limestone, the Coal Measures, and the Lias. The following details are chiefly from the "Memoirs of the Geological Survey of Great Britain:"—

THE ORES OF THE CARBONIFEROUS LIMESTONE.

In this formation, consisting in the North of England of strata of limestone, gritstone, and shale, the argillaceous carbonate occurs in some of the bands of shale in strata like those more abundant in the Coal Measures. The hydrous sesquioxide, or brown hæmatite, appears in some instances also to form layers, although its mode of occurrence is at present more doubtful. A stratum of the carbonaceous blackband ore has been worked at Haydon Bridge. Some of the lead veins of the Alston district are charged with brown iron ore, and in other parts with the sparry carbonate, and in both cases have

of late been successfully worked. The red hæmatite of Whitehaven occurs in the same Carboniferous Limestone near the outcrop of the slaty rocks on which that formation rests. This fine and pure ore occurs in magnificent beds, 15, 30, and even 60 feet in thickness, usually subterraneous, but occasionally at the surface. Very little of this is smelted on the spot, owing to the want of fuel—not more in 1857 than 56,511 tons; but in the same period 193,850 tons were shipped at Whitehaven, and 66,651 tons conveyed by railway, to Wales, Staffordshire, Scotland, Newcastle, etc. The hæmatite is also worked at Stainton, Lindale, Ricket Hills, Elliscales, and Mousell. At the Park and Roanhead Mines "you may proceed 400 to 500 feet in either direction in one solid mass of this valuable substance, and nothing has as yet been seen of the bottom of it."

In Wales, extensive deposits of hæmatite occur in Glamorganshire, in the upper beds of the Carboniferous Limestone; and of late these have been extensively worked.

THE IRONSTONES OF THE COAL MEASURES.

The ores in the Coal Measures consist almost exclusively of the argillaceous clay-ironstone in concretionary nodules. They are not smelted in their raw state, but are first calcined either in kilns or in heaps. In the Yorkshire coalfield they are not plentiful, though a sufficiency is found to supply furnaces in which a peculiar bed of coal is employed, remarkably free from sulphur; and this, with studious care in the manufacture, results in the production of the fine qualities of iron known as Lowmoor, Bowling, Farnley, etc.

In the Derbyshire coalfield, of a total thickness of 1600 feet, the same valuable deposits of argillaceous ore occur in great abundance.

In Staffordshire, a portion of the coalfield has been so productively worked that the character of the country has been

changed; and the number of smelting and puddling furnaces, the refuse of metallurgical operations, the coking heaps, all partaking of a general sooty character, have led to the application to this district of the epithet "the black country." "In no other coalfield of the United Kingdom," says Mr. Beete Jukes, "is a thickness of 30 feet of coal to be found together; while in South Staffordshire twelve or thirteen beds of coal rest one upon the other, with but very slight *partings* of shale between them, making up often that thickness, and sometimes more. In the same way I believe the quantity of ironstone to be found in some parts of this district, within a vertical space of 100 or 150 yards, is greater than is known anywhere else."*

Amongst the ores of the coal measures are three kinds, which till latterly have been rejected on account of their supposed comparative worthlessness. They possess the character of compactness, and are all more or less of a dark colour, which is probably produced by the coaly matter with which they are united. The third variety contains iron pyrites $Fe\ S_2$, thus exhibiting a yellowish colour, and from this appearance the miners have termed these ores *brass*.

Messrs. Nicholson and Dr. Price have analysed this description of iron, and state that the ores have respectively the following composition:—

	First Variety.	Second Variety.	Third Variety.
Carbonate of iron	68·71	59·73	17·74
Carbonate of manganese	0·42	0·37	...
Carbonate of lime	9·36	11·80	14·19
Carbonate of magnesia	11·80	15·55	12·06
Iron pyrites	0·22	trace.	49·72
Phosphoric acid	0·17	0·23	trace.
Coaly matter	8·87	9·80	6·10
Clay	...	2·70	...
	99·55	100·18	99·81

* Memoirs of the Geological Survey of Great Britain: "The Iron Ores of South Staffordshire," 1858.

As these ores contain a considerable amount of lime and magnesia, they might therefore, if judiciously treated, be worked as economically as the other spathic iron ores of the Welsh district.

"An interesting feature in these ores is their fusibility during calcination on the large scale. When this process is conducted in heaps, the centre portions are invariably melted. This, considering the almost entire absence of silica, is apparently an unexpected result. The fused mass is entirely magnetic and crystalline. Treated with acids, it dissolves with great evolution of heat.

"The following is its composition :—

"Protoxide of iron	38·28
Sesquioxide of iron	32·50
Protoxide of manganese	0·38
Lime	12·84
Magnesia	13·87
Phosphoric acid	0·17
Sulphur	0·23
Silicic acid	1·20
Alumina	0·51
	100·08

"From the above analysis, it is probable that the fusibility of the compound is owing to the magnetic oxide of iron acting the part of an acid. When thoroughly calcined and unfused, the ores retain their original form ; and if exposed to the air for any length of time, crumble to powder, from the absorption of water by the alkaline earths."—*Price and Nicholson.*

In Scotland, the blackband, first discovered by Mushet in 1801, is the ore chiefly worked, and this, coupled with the application of the hot-blast by Neilson, has made Scotland an iron producing country. The blackband is an impure carbonate, mingled with large quantities of bituminous and carbonaceous matter, or, more strictly speaking, all of these ores consist of the carbonate of the protoxide of iron, united with

varying proportions of the carbonates of manganese, magnesia and lime, and clay, and in the case of the blackbands of Scotland of coaly matter.

THE ORES OF THE OOLITE.

Mr. Edward Hull, in pursuing the Geological Survey, found considerable beds of silicious iron ore belonging to the Lower Oolite, and a calcareous ore in the Upper Lias, in the neighbourhoods of Banbury, Deddington, and Woodstock. The Woodstock ore, or Blenheim ore, as Mr. Hull has termed it, is almost identical in geological position and nature with the Cleveland ore of Yorkshire. It contains only 0.55 per cent of phosphoric acid, and of metallic iron about 32 per cent.

Since the above was written, an ore which was then comparatively unknown has been worked with good results, and that is the green Lias ore of the Cleveland districts, occurring on the Eston Hills in a bed 15 feet thick. This ore is roasted before being smelted, and is chiefly used for the manufacture of water pipes, the iron being peculiarly adapted for that purpose.

Dr. Price, in the metallurgical operations of the Exhibition, states "that the most important brown oxide of iron is that from the Forest of Dean." The best known is the "black brush" ore, of which the analysis is as follows :—

Sesquioxide of iron	89·28
Water	9·74
Silicic acid	0·98
Phosphoric acid	trace.
	100·00

It makes a strong and pure iron, which, amongst other purposes, is extensively used for the manufacture of sheet iron for tin plates. Other hydrated oxides of iron are worked in the south of Devon and in Northamptonshire. The ores

from the latter district contain phosphoric acid, which detracts from their value. Large deposits of similar ore occur in many parts of England, but they have not, as yet, been much explored. The sparry carbonate, "spatheisenstein" of the Germans, so much in use in the iron districts of Westphalia and Styria, and which yields the "spiegeleisen"—the iron from which the raw or natural steel is manufactured—was, until the last few years, only smelted at the Tow Law Works, near Weardale, in Durham, where a limited supply was obtained. Since 1851, however, another source of this valuable mineral has been discovered and largely worked on the Brendon Hills, Somerset, whence it is shipped to Newport, and smelted at the Ebbw Vale Ironworks.

The following is the analysis of this ore by Dr. Price and Nicholson :—

Protoxide of iron	43·94
Protoxide of manganese	12·88
Magnesia	4·00
Carbonic acid	39·18
	100·00

When smelted with a light burthen, the sparry ore yields a pig-iron of highly crystalline structure and steely lustre, rich in manganese and carbon. Pig-iron of this composition naturally wastes very much in puddling, but the quality of the wrought iron which it makes is excellent.

In Northampton a silicious carbonate is being worked.

The following Table, which exhibits the chemical composition of British iron ores, as given in the "Memoirs of the Geological Survey," will not be unacceptable to the general reader :—

TABLE *exhibiting the Composition of Average Samples of British Iron Ores, from the "Memoirs of the Geological Survey."*

	II. Weardale Spathose Ore, Rispey.	III. Compact Red Hæmatite, Cleator Moor.	XXI. Cleveland Ore, chiefly Carbonate.	VII. White Bed Mine, Bierly, Yorkshire, Clay Ironstones.	XXVII. Gubbin Ironstone, Cannock, Dudley.	XXXI. Whitestone, Rough Hay Colliery, Darlaston, Clay Iron Ore.
Protoxide of iron .	49·47	...	39·92	35·38	45·86	33.92
Peroxide of iron . .	...	95·16	3·60	1·20	...	2·77
Protoxide of manganese	2·42	0·24	0·95	0·94	0·96	0·77
Alumina . . .	trace.	...	7·86	0·80	0·42	0·67
Lime	3·47	0·07	7·44	2·78	1·17	2·45
Magnesia . . .	3·15	...	3·82	2·22	1·65	4·11
Carbonic acid . .	37·71	...	22·85	25·41	31·02	26·89
Phosphoric acid . .	trace.	trace.	1·86	0·48	0·21	0·35
Sulphuric acid . .	trace.	trace.	trace.	trace.	trace.	...
Silica	0·91	...	7·12	...	0·42	0·09
Bisulphide of iron .	0·08	trace.	0·11	0·18	0·10	0·15
Organic matter . .	trace.	...	trace.	0·23	0·90	0·47
Potash . . .	...	...	0·27	...	...	0·14
Water in combination .	...	...	2·97	1·11	1·08	0·98
Water, hygroscopic .	...	...	...	0·74		0·42
Insoluble residue, chiefly silica .	3·83	5·68	1·64	28·00	15·90	25·55
Iron, total amount .	38·56	66·60	33·62	28·76	35·99	28·87

The ores principally employed are the clay-ironstones and carbonates of blackbands, which are found interstratified with the coal-fields of Ayrshire, Lanarkshire, Shropshire, South Wales, and other parts, and these vary in richness in different localities, according to position and the amount of silica, clay, and other foreign matter with which they are associated. The chemical composition of three varieties of the ore used in Lanarkshire, is given by Dr. Colquhoun as follows :—

	No. 1.	No. 2.	No. 3.
Protoxide of iron . .	53·03	47·33	35·22
Carbonic acid . . .	35·17	33·10	32·53
Silica	1·40	6·63	9.56
Alumina	0·63	4·30	5·34
Lime	3·33	2·00	8·62
Magnesia	1·77	2·20	5·19
Peroxide	0·23	0·33	1·16
Bituminous matter . .	3·03	1·70	2·13
Sulphur	0·00	0·22	0·62
Oxide of manganese . .	0·00	0·13	0·00
Moisture and loss . .	1·41	2·26	0·00
	100·00	100·00	100·37

The carbonic acid in the above ores may be partly combined with the lime as carbonate of lime, as well as with the protoxide of iron.

M. Berthier gives, according to Dr. Ure, the following analyses of the English and Welsh ironstones of the Coal Measures :—

	Rich Welsh Ore.	Poor Welsh Ore.	Dudley Rich Ore or Gubbin.
Loss by ignition	30·00	27·00	31·00
Insoluble residuum . .	8·40	22·03	7·66
Peroxide of iron	60·00	42·66	58·33
Lime	0·00	6·00	2·66
	98·40	97·69	99·65

Calculating the amount of carbonate of iron and metallic iron indicated by the above analyses, we have—

Carbonate of iron . .	88·77	65·09	85·20
Metallic iron . . .	42·05	31·38	40·45

The richness of the above ironstones would be about 33 per cent of iron. In the process of roasting, 28 per cent of the ore is dissipated.

Mr. Mitchell gives also the following assays of clay-ironstone and blackband ore, as under :—

	Clay Ironstone, Leitrim, Ireland.	Blackband Carbonate Ore.
Protoxide of iron	51·653	20·924
Peroxide of iron	3·742	·741
Oxide of manganese	·976	1·742
Alumina	1·849	14·974
Magnesia	·284	·987
Lime	·410	·881
Potash	·274	trace.
Soda	·372	trace.
Sulphur	·214	·098
Phosphoric acid	·284	·114
Carbonic acid	31·142	14·000
Silica	6·640	26·179
Carbonaceous matter	2·160	16·940
Loss		2·420
	100·000	100·000

In North Lancashire and Cumberland, the red hæmatite ores are now extensively worked, and great quantities are yearly shipped from Whitehaven, Ulverstone, etc., to Staffordshire, South Wales, and Scotland, for mixing with the poorer argillaceous and blackband ores. In Cumberland and North Lancashire, no less that 592,390 tons were raised in 1857 for this purpose, and the greater portion was exported from those districts.

In addition to these exports, about 25,000 to 30,000 tons are smelted by the hot-blast at Cleator, in the neighbourhood of Whitehaven. It produces a strong and ductile iron, considered highly valuable for mixing with the weaker irons. These ores have been carefully analysed, and contain :—

Peroxide of iron	90·3
Silica	5·0
Alumina	3·0
Lime	trace.
Magnesia	trace.
Water	6·0
	104·3

Or about 62 per cent of metallic iron.

In Ireland there are vast deposits of iron ore, of great richness, though as yet but little worked. Some of these, such as the ores worked at the Arigua Mines, and the Kidney ores of Balcarry Bay, yield nearly 70 per cent of iron. If these mines were worked more extensively, and if peat fuel were used in the smelting operations, the iron would probably be of the very best quality, and might rival the famed Swedish charcoal metal. Of this there is now every reason to hope, as the establishment of railway communication with almost every part of Ireland will open out the immense peat bogs of that country, and facilitate the introduction of vegetable fuel for the reduction of the ores, and create a large and important addition to other branches of Irish industry. In a communication to the writer from Mr. M'All, he states :—"I have sent you samples of two kinds of iron ore; one is the red, the other the purple hæmatite. There are strata which are inexhaustible, and the ore can be raised and delivered at the furnace for less than a shilling a ton; the peat or vegetable carbon is equally cheap and abundant. Limestone of the purest quality is also close at hand, and can be delivered at the furnace at ninepence per ton. On account of the purity of these materials, iron of the greatest strength and ductility can be made, which from its non-liability to corrode, would be admirably adapted for naval and marine purposes." Ireland is, therefore, according to Mr. M'All and others, in a condition to supply large quantities of excellent iron.

The Iron Ores of France.—France possesses an abundant supply of iron ore, but, on account of the scarcity of coal, the manufacture has been greatly restricted in extent. The introduction of railway communication is however rapidly removing this difficulty, and the operations of smelting are greatly on the increase. The railroad has enabled the French ironmaster to substitute coal for charcoal in the reduction of the iron ores, and in consequence an immense increase has

taken place in the production of pig and manufactured iron. The ores are found in beds or strata in the Jura range; accumulated in kidney-shaped concretions in the fissures of the limestone; or dispersed over the surface of the ground, and but slightly covered with sand or clay.

They are found in the departments of the Yonne, the Meuse, and the Moselle, and indeed may be traced from the Pas de Calais on the north to the Jura on the south, indicating throughout an abundant and ample supply.

The present increased production of iron in France is chiefly due to the introduction of coal in smelting, but it may also be traced in some measure to the encouragement given by the Government to that branch of industry, and to the enterprise of such men as M. de Gallois and M. Dufrènoy, who have exerted themselves to extend its manufacture in that country. M. de Gallois resided in England for several years immediately subsequent to the peace of 1815; and having obtained admission into the different iron-works here, he returned to France and established the works at St. Etienne, now probably the largest and most extensive in that country.* The production of crude pig-iron in France is now little short of 1,000,000 tons annually; but the demand for railways, rolling-stock, bridges, iron ships, girders, and other constructions, is so great that large quantities of iron are still annually imported from this country.

The Iron Ores of Prussia.—Valuable deposits of the black-band and clay carbonate ores are found interstratified with the great coal-field of Ruhr; and the bog-iron and hæmatite ores

* The Universal Exhibition of the year 1855 fully justifies the remarks in reference to the great increase of the iron trade of France. Any person in the least conversant with the imperfect machinery and processes of the iron manufacture as it existed in France some years since, could not have been otherwise than struck with the improved character of those exemplified in the Paris Exhibition. In no country (probably not excepting even this) has so great progress been made in so short a time, in advancing from a state of comparative rudeness to one of considerable perfection, as in France.

are found in considerable profusion in Rhenish Prussia and other parts. In Upper Silesia, on the Vistula, and the Oder, large deposits of coal and iron are found in juxtaposition, and are worked to a considerable extent.

The consumption of iron is not so great as in France, though it is increasing rapidly, as may be seen from returns recently given by the British Chargé d'Affaires at Berlin. These returns show that the amount of iron ore raised in Prussia has increased from 1,495,516 tons in 1853, to 2,144,509 tons in 1854; this has taken place in nearly all the producing districts, but chiefly on the Rhine, where the demand has increased from 719,684 to 1,068,656 tons; in Westphalia, from 146,320 to 330,014 tons; in Silesia, from 563,739 to 650,369 tons; in Lower Saxony and Thuringia, from 51,963 to 70,676 tons; in Prussian Brandenburg, from 8084 to 12,731 tons; and in the Upper Zollverein, from 6736 to 12,063 tons.

The Iron Ores of Austria, Belgium, etc.—In Austria, all the iron is smelted with charcoal or carbonised peat, and is in consequence of the finest quality; it may be applied to every description of manufacture, from the most ductile wire to the hardest steel. The production is, however, small. The ores are found in Hungary, Styria, Moravia, and Upper Silesia.

In Belgium, both coal and iron are found in equal abundance, and are worked at Charleroi, Liege, and at other places. The ores, which are chiefly hæmatite, are derived from the limestone at the base of the coal measures. A species of bog ore is also extensively used, which is found near the surface, and is said to be washed to free it from impurities.

The Ores of Sweden, etc.—The superiority of the Swedish iron has long been acknowledged, and till recently it has been unrivalled. This arises not only from the purity of the ore—chiefly the magnetic oxide of iron—but in consequence of its being smelted with charcoal only. The quantity is, however, restricted, as the ironmasters are allowed by law only a certain

number of trees per annum, in order that the forests may not be totally destroyed. Coal does not exist in either Sweden or Norway.

In addition to the magnetic oxide ores, there are other descriptions of less pure ores found in several of the Swedish lakes and streams, called lake ores, and which have been used from time immemorial for the manufacture of iron. They are of five kinds, known from their appearance as—1. Perl-malm (pearl ore); 2. Borr-malm (so called from its resemblance to the rough heads of the burdock plant); 3. Penning-malm (money ore); 4. Skragg-malm (cake ore); and 5. Krut-malm (gunpowder ore). From the entertaining and instructive description of these ores written especially for the Exhibition of 1862 by Mr. C. W. Sjögreen, of the Bruzaholm Ironworks, we learn that they are found in large beds in the shallow parts of large and deep lakes. Mr. Sjögreen, who has studied their formation, believes them to be of infusorial origin, and is convinced that the lake ores, like certain shell-fish, might be propagated in other waters than those of Sweden, where conditions existed congenial to their growth. He states it to be a well-known fact, that the lake ore is reproduced in places where, years before, the supply had been exhausted. The ores contain from 25 to 50 per cent of iron-gunpowder ore; the most prized being the richest and yielding the best iron. They are phosphatic, and the iron smelted from them, although not of the best quality, is found admirably adapted for certain foundry purposes. It is not only used extensively in Sweden, but is also exported to Prussia. As the collecting of the ores provides employment during the winter for the poor of the province of Smaland, and a novel feature in the metallurgy of iron, the following account of it may interest our readers :—

"Towards the end of autumn, or when the lakes have become ice-bound to the depth of two or three inches, the collector sets out on his search. For that purpose he makes

little holes in the ice along the slopes of the shallows. Through these holes he puts down a long pole, with which he gently strikes the bottom, and partly by hearing, partly by the sense of feeling, ascertains whether any ore or not is to be found in the place; but long practice is needed in order to pursue the work with success.

"The extent of the layer being known, the collector marks the boundaries of the same by means of little twigs stuck into the ice to prevent others from encroaching on his territory, now considered as lawfully acquired property. In this manner the collector marks out as many places as he intends to work during the winter, and proceeds upon the ice getting strong enough to collect the ore, this being performed in the following manner:—At the outer boundary of the marked 'claim,' a round hole of about three feet in diameter is cut through the ice, and through this hole a riddle of perforated iron plate fixed to a long pole is put down and sunk to the bottom of the lake. The next tool consists of an iron rake about two feet broad, also fixed to a pole. With this rake the collector, by means of certain manipulations, collects the ore in a heap at the bottom, and by means of another rake about 6 inches broad, he fills the riddle, which is then got up, and its contents, consisting of ore, mud, clay, and sand, piled into a heap on the ice. In order that the ore might be separated from these impurities, the mass is put into another iron riddle, and by sinking this two or three inches below the surface of the water and giving it a rocking motion, the collector sifts as it were the dirt from the ore, and piles the latter on the ice, whence it is brought to the nearest blast-furnace. Two labourers are generally associated, the one being busy collecting and the other washing the ore. If the ore is tolerably plentiful, a man generally gathers from half a ton to a ton in a day, all depending of course as well upon his skill as upon the quality of the ore and the materials composing the bottom; for, if the

latter consists of mud, the gathering is much more easily performed than if the ore is resting on clay, stones, or sand. The ore happens sometimes to be covered with a thin layer of mud, in which case great skill and ingenuity is required, not only to discover it, but also to uncover the same so as to make it possible to be got up."

Turkish Iron Ores.—In 1844 some experimental researches were undertaken by myself at Manchester, at the request of the Sublime Porte, in regard to the properties of iron made from the ores of Samakoff in Turkey. The ores were strongly magnetic, and contained, according to Dumas and others, 62 to 64 per cent of iron. They consisted of—

One atom iron	28 + one atom oxygen		8 =	36
Two atoms iron	56 + three atoms oxygen		24 =	80
Iron .	84	Oxygen .	32	116

Some of these ores have been smelted with charcoal, and some very fine specimens of iron and steel produced. The manufacture is, however, in a languid state in Turkey; and although smelting furnaces, blowing apparatus, forges, rolling-mills, etc., were prepared and sent out from this country, they are to a great extent useless among a people who have deeply rooted prejudices, habitual inactivity, and everything to learn in all those habits of industry which indicate the rising prosperity of an energetic and an active people.

The Iron Ores of America.—The magnetic, hæmatite, and clay ironstones abound in the United States: the magnetic ores being worked in New England, New York, and New Jersey; the hæmatite in Pennsylvania, New York, New Jersey, and other localities; but the greater part of the manufacture must eventually establish itself in the valley of the Mississippi, west of the Alleghany range, where vast deposits of coal and iron exist, though at present but imperfectly known or de-

veloped. The ores in most of these districts are smelted with a mixture of charcoal and anthracite, and the usual limestone flux, and produce a very excellent quality of iron.

The following is an analysis of magnetic ore from the gneiss near New York :—

Protoxide of iron	25·40
Peroxide of iron	70·50
Oxide of manganese	1·60
Silica and loss	2·50
Metallic iron	68·50

In the mineral and geological department of the Exhibition of 1862, were exhibited striking specimens of iron ores from the colonies, amongst which was the remarkable collection from Canada, consisting of oxide, red hæmatite, and bog ore. The thickness of some of the beds from which the specimens were taken is worthy of notice. The "Big Bed" of the Marmora mine is 500 feet thick, in layers, one of them measuring 100 feet thick. In Mud Lake mine there is a bed 200 feet thick occurring in gneiss, and at Hull one 90 feet thick. All these consist of deposits of magnetic oxide. Bog iron ore is found in the neighbourhood of the Bastican and St. Lawrence rivers, and a remarkable ore is also found at St. Urbans, Bay of St. Paul, consisting, according to Dr. Price, of—

Oxide of titanium	48·60
Protoxide of iron	46·44
Magnesia	3·60
	98·64

The great drawback to Canada is the absence of coals, which necessitates the ore being sent to some distance to be smelted, and were it not for this drawback Canada would rank foremost as an iron-producing country.

In Nova Scotia some of the richest ores yet discovered

occur in exhaustless abundance. The iron manufactured from them is of the very best quality, and is equal to the finest Swedish metal. The specular ore of the Acadian Mines, Nova Scotia, is said by Dr. Ure to be a nearly pure peroxide of iron, containing 99 per cent of the peroxide, and about 70 per cent of iron. When smelted, 100 parts yield 75 of iron, the increase in weight being due to combined carbon. The red ore Dr. Ure states to be analogous to the kidney ore of Cumberland, and to contain—

	(1)	(2)
Peroxide of iron	85·8	84·4
Silica	8·2	8·0
Water	6·0	7·6
	100·0	100·0

The Acadian ores are situated in the neighbourhood of large tracts of forests, capable of supplying almost any quantity of charcoal for the manufacture of the superior qualities of iron and steel. Several specimens of iron from these mines have been submitted to direct experiment, and the results prove its high powers of resistance to strain, ductility, and adaptation to all those processes by which the finest descriptions of iron and steel are manufactured.

The difficulties which the Government have had to encounter, during the last two years, in obtaining a sufficiently strong metal for artillery, are likely to be removed by the use of the Acadian pig-iron. Large quantities have been purchased by the War Office, and experiments are now in progress, under the direction of Lieutenant-Colonel Wilmot, Inspector of Artillery, and the writer, which seem calculated to establish the superiority of this metal for casting every description of heavy ordnance.

There are also some very rich ores at the Nictau mines, as the following analyses by Dr. Jackson show. They contain impressions of Silurian tentaculites, spirifers, etc.—

	Brown Ore, somewhat magnetic.	Red Iron Ore.
Peroxide of iron . .	70·20	64·40
Silica	14·40	19·20
Carbonate of lime . .	5·60	5·40
Carbonate of magnesia .	2·80	3·20
Alumina	6·80	1·20
Oxide of manganese .	·40	4·40
Water	·00	2·40
	100·20	100·20
* Gain from oxygen.	·20*	·20†
† Over-run, probably carbonic acid from carbonate of lime.	100·00	100·00

As our limits are circumscribed, it will not be necessary to extend this section further. Suffice it therefore to observe, that in all countries nature has, for a beneficent purpose, interlaid and interstratified the whole surface of the globe with this useful and indispensable material; and it would ill bespeak that high intelligence with which man is endowed if he did not avail himself of, and turn to good account, the immense stores of mineral treasures which are so profusely laid at his feet.

CHAPTER III.

THE FUEL.

THE inquiry into the properties and composition of the ores of iron, and the processes employed for their reduction and subsequent conversion into bars and plates, would be incomplete unless accompanied by descriptive analyses of the fuel by which they are fused. Indeed, the results of the operations of smelting, puddling, etc., are so intimately dependent on the quality of the fuel employed, as to render a knowledge of its constituents essential to the manufacture of good iron.

Charcoal was at first universally employed in the manufacture of iron; on account of its purity as compared with other kinds of fuel, and its strong chemical affinities and consequent high combustibility, it is of very superior value, where it can be obtained in large quantities at a moderate cost. This, however, is rarely the case, and hence its use is restricted within very narrow limits in most countries. Charcoal is the result of several processes, in each of which the object is to increase the amount of fuel in a given bulk. The wood being cut into convenient lengths, and piled closely together, in a large heap, the interstices being filled with the smaller branches, and the whole covered with wet charcoal powder, is then set on fire. Care is taken that only sufficient air is admitted to consume the gaseous products of the wood, so as to maintain the high temperature without needlessly consuming the carbon. After the whole of the gaseous products have been separated, and the carbon and salts only

are left, the access of air is prevented, and the heap allowed to cool.

Another and better process is to throw the wood into a large close oven or furnace, heated either by the combustion within it, or by a separate fire conducted in flues around it. By this process, not only is the yield greater and of better quality, from the slower progress of the operation, but the products of the distillation may be preserved and employed for a great variety of purposes. The following results of some experiments by Karsten show the difference in yield of very rapid and very slow processes :—

Wood.	Charcoal produced by quick carbonisation.	Charcoal produced by slow carbonisation.
Young Oak . .	16·54	25·60
Old „ . .	15·91	25·71
Young Deal . .	14·25	25·25
Old „ . .	14·05	25·00
Young Fir . .	16·22	27·72
Old „ . .	15·35	24·75
Mean . .	15·38	25·67

These, on the average, give for the quick process 15·3, and for the slow 25·6, being in the ratio of 1 : 1·67, or 0·67 in favour of the slow process.

Peat.—This material seems likely to come into use for smelting iron in countries such as Ireland, where neither coal nor wood are found in abundance. It is purer and less objectionable than coal, and if properly dried, compressed, and carbonised, would prove a very valuable fuel for the reduction of such ores as we have already described in the section on the iron ores of Ireland. It is carbonised in the same way as the charring of wood. The great objection to peat as a fuel for manufacturing purposes is its lightness and friability. In Ireland, and other places, this has been sought to be overcome by the compression of the peat in powerful

hydraulic presses. Thus compressed, the peat loses two-thirds of its volume, and two-fifths of its weight, through the expulsion of part of its water.

Large quantities of peat are carbonised on the Continent in the Vosges, Bavaria, Saxony, and France, and employed in the smelting of iron. The yield of peat charcoal does not exceed 30 per cent of the raw material when it is charred in open heaps, nor 40 per cent when the carbonisation is effected in closed kilns. The products of the distillation are sometimes collected, and form valuable articles of commerce.

Coke.—Before the introduction of the hot-blast, this material was used to a very great extent in the manufacture of iron; it is prepared from coal in the same way that charcoal is prepared from wood, the operation being called the coking or desulphurising process. The heaps do not require so careful a regulation of the admission of air as those of charcoal, on account of the comparatively incombustible character of the coke. Sometimes the heaps are made large, with perforated brick chimneys, to increase the draught through the mounds; at other times they are formed into smaller heaps, and the conversion takes place without the intervention of flues. The more usual and economical plan is, however, the employment of close ovens, by which process a great saving is effected, the yield being from 30 to 50 per cent in the one case, and from 50 to 75 in the other, according to the nature and quality of the coal.

Coal.—The hot-blast has enabled the ironmasters to use raw coal in the blast-furnaces, the great heat of the ascending current of the products of combustion coking it as it falls in the furnace. The sulphur, however, and other deleterious ingredients, do not appear to be so completely got rid of as when the coal is used in the shape of coke; and it appears probable, that even with the hot-blast, the separate process of

coking might be advantageously used, on account of the greater purity of the iron produced.

The facilities of different countries for producing iron depend largely upon the quantity of coal found in their borders. The source of English pre-eminence in this manufacture is due to the large and accessible coalfields, and their close association with the iron ores. It has been calculated that there are 8139 square miles of bituminous coal, and 3720 of anthracite, in Great Britain, or 1-10th of the whole area of these islands. On the other hand, in France there are only 1719 square miles, or the 1-118th of the area; in Spain, 3408 miles, or the 1-52d; in Belgium, 518 square miles, or the 1-22d. America contains, however, the largest coalfields, British America having 18,000 square miles, or 2-9ths of its whole area; the United States 133,132 square miles of bituminous coal, or 1-17th of the area, and Pennsylvania 15,437 miles of anthracite, or 1-3d of the whole area. (*Taylor.*)

The properties of the bituminous or caking coals are well known; they form the prevailing variety of the British coalfields, and contain about 50 per cent of bituminous matter. They are the most important variety for both household and general purposes, make excellent coke, and are employed in the raw state for smelting in the blast-furnaces in many districts, but more especially in Scotland.

Next in rank comes the splint coal, which occurs in Derbyshire, South Yorkshire, and other localities. It belongs to the same carboniferous formation, but is much inferior to the caking coal in every respect.

The following Tables, selected from various sources, give the composition of the different kinds of fuel, all of which are applicable to the reduction and fusion of the iron ores :—

Fuel.	Locality.	Specific gravity.	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ashes in 100 parts.	Authority.
Splint Coal.		1·290	75·00	6·25	18·75	...	Thomson.
		1·266	70·90	4·30	24·80	...	Ure.
	Newcastle, Wylam	1·302	74·823	6·180	5·085	13·912	Richardson.
	Glasgow . . .	1·307	82·924	6·491	10·457	1·128	
Cannel Coal.		1·272	64·72	21·56	13·72	...	Thomson.
		1·228	72·22	3·93	23·85	...	Ure.
	Lancashire, Wigan	1·319	83·753	5·660	8·039	2·545	Richardson.
	Edinburgh, *Parrot coal.*	1·318	67·597	5·405	12·432	14·566	
Cherry Coal.		1·263	74·45	12·40	13·15	...	Thomson.
	Newcastle, Jarrow	1·266	84·846	5·048	8·430	1·676	Richardson.
	Glasgow . . .	1·286	81·208	5·452	11·923	1·421	
Caking Coal.	Newcastle, Garesfield . . .	1·280	87·952	5·239	5·416	1·393	
	Durham, South Hetton . . .	1·274	83·274	5·171	3·036	1·519	
		1·269	75·28	4·18	20·54	4·670	Thomson.
Anthracite.	Swansea . . .	1·348	92·56	2·330	2·530	1·720	Regnault.
	„ . . .	1·270	90·58	2·600	4·100	...	Jacquelin.
	South Wales . .	...	94·05	3·380	2·570	...	Overman.
	Pennsylvania . .	1·462	90·45	2·430	2·450	. 4·670	Regnault.
	„ . .	...	94·89	2·550	2·560	...	Overman.
	Massachusetts. Worcester . .	...	28·35	0·920	2·150	68·65	
	Wales	1·349	92·79	3·14	2·53	1·45	Schafhaeutl.
Peat.	Vulcaire . . .	...	57·03	5·630	31·760	...	Regnault.
	Long	...	58·09	0·930	31·370	...	
	Camp de Feu .	...	57·79	6·110	30·770	...	
	Cappage . . .	...	51·05	6·85	39·55	2·55	Dr. Kane.
	Kilbeggan . .	...	61·04	6·67	30·46	1·83	
	Kilbakan . . .	...	51·13	6·33	34·48	8·06	

The subject of the chemical composition of coal has been most elaborately worked out by Dr. Lyon Playfair in a report to the Admiralty, published in the Memoirs of the Geological Survey of Great Britain. We must refer the reader to the original memoir for the details of the elaborate analyses

carried out under his direction; all that can be done here is to present a brief summary of his results:—

Average Composition of Coals from different Localities.

Locality.	Specific gravity.	Carbon.	Hydrogen.	Nitrogen.	Sulphur.	Oxygen.	Ash.	Per centage of Coke left by each Coal.
36 samples from Wales	1·315	83·78	4·79	0·98	1·43	4·15	4·91	72·60
18 „ Newcastle	1·256	82·12	5·31	1·35	1·24	5·69	3·77	60·67
28 „ Lancashire	1·273	77·90	5·32	1·30	1·44	9·53	4·88	60·22
8 „ Scotland	1·259	78·53	5·61	1·00	1·11	9·69	4·03	54·22
7 „ Derbyshire	1·292	79·68	4·94	1·41	1·01	10·28	2·65	59·32

According to Knapp, peat contains from 1 to 32 per cent its weight of ash. In coal we have the following from Mr. Mushet's analyses:—

	Specific Gravity.	Carbon.	Ashes.	Volatile matter.
Welsh furnace coal . .	1·337	88·068	3·432	8·300
„ „ „ . .	1·393	89·709	2·300	8·000
„ slaty „ . .	1·409	82·175	6·725	9·100
Derbyshire furnace coal .	1·264	52·882	4·288	42·830
„ cannel coal .	1·278	48·362	4·638	47·000

The following Table indicates the composition of the ashes of coal, a subject of the highest importance to the metallurgist, as from this source a part of the impurities are derived. They are quoted from Mr. Phillips:—

Locality.	Silica.	Alumina and Oxide of Iron.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Total per-centage.	Per-cent-age of Ash in Coal.	Per-cent-age of Coke in Coal.
Pontypool	40·00	44·78	12·00	trace	2·22	0·75	99·75	5·52	64·8
Bedwas .	26·87	56·95	5·10	1·19	7·23	0·74	98·08	6·94	71·7
Porthmawr	34·21	52·00	6·20	0·66	4·12	6·63	97·82	2·91	63·1
Ebbw Vale	53·00	35·01	3·94	2·20	4·89	0·88	99·92	14·72	77·5
Coleshill .	59·27	29·09	6·02	1·35	3·84	0·40	99·97	10·70	...
Fordell . Splint . Wallsend .	37·60	52·00	3·73	1·10	4·14	0·88	99·45	1·50	52·03
Elgin .	61·66	24·42	2·62	1·73	8·38	1·18	99·99	4·0	58·45

The following Table of the heating power of various kinds of fuel, from Knapp's Chemical Technology, is not without interest; in practice, however, only a portion of the absolute heating power is made available:—

	Authority.	Lbs. of water heated from 0° to 100° C. by 1 lb. of fuel.
Charcoal—		
Average	Berthier	68·0
Peat from Allen in Ireland, Upper	Griffith	62·7
Pressed		56·6
Lower		28·0
Peat charcoal—		
Essone	...	50·7
Framont and Champ de Feu	Berthier	58·9
Coke—		
St. Etienne	Berthier	65·6
Besseges		64·3
Rive de Gier		58·9
Brown coal—		
Mean of seven varieties	Berthier	50·3
Cannel coal, Wigan	Berthier	64·1
Cherry, Derbyshire		61·6
Cannel, Glasgow		56·4
„ Lancashire		53·2
Durham		17·6
Gas coke, Paris—		
Anthracite	Berthier	50·3
Pennsylvania		69·1
Mean of five varieties		67·4

In concluding the observations on fuel, we may notice that the various kinds of coal are classed by mineralogists as the bituminous, and stone or anthracite coal. The first class is chiefly employed for the purpose of smelting, but the introduction of the hot-blast has effected a change as regards the anthracite, which is now coming largely into use both in this country and America. Mr. Crane of South Wales was the first who attempted the reduction of iron ores by anthracite, and Mr. Budd, at his works at Ystalyfera, followed success-

fully in the same path. To these two gentlemen the public are indebted for having surmounted the obstacles to the employment of this fuel for smelting iron.

On the occasion of a visit to Mr. Crane's works, nearly twenty years ago, the writer had an opportunity of inspecting some specimens of anthracite which had passed through the furnace, and been in contact with the minerals at the temperature of fusion for forty-eight hours, without having suffered decomposition, and were found to be charred to a depth of only three-fourths of an inch, the interior being of a perfectly shining and black colour, and quite unaffected by the heat of the furnace.

We may mention here Mr. Crace Calvert's process for the purification of coke intended for smelting purposes. It is well known how injurious to the quality of iron is the presence of phosphorus and sulphur, both of which are present often in considerable quantities in the ores and fuel. Sulphur has a tendency to make the iron red short, and phosphorus to make it cold short; and this effect is so deleterious in most cases, that the Yorkshire irons appear to owe their signal superiority to the fact that the bed of coal employed in their reduction and manufacture is free from these ingredients. Mr. Calvert employs chlorine, hydrochloric acid, or chlorides, either by introducing them into the blast-furnace, or in contact with the ores when roasted, or into the coking ovens. Chloride of sodium is preferred in the proportion of 58 parts of the chloride to 16 parts of sulphur, or 32 parts of phosphorus, in the ores or coal. The effect is to remove to a great extent the phosphorus and sulphur with which the sodium unites to form a slag.

CHAPTER IV.

THE REDUCTION OF THE ORES.

THE processes for the manufacture of iron, as we have already pointed out, are of two distinct kinds—those of cementation and those of smelting. The product of the former is imperfectly malleable iron; that of the latter, cast-iron, or iron combined with more or less carbon.

Dr. Percy appears to have selected a great deal of valuable information on the primitive progress of iron-smelting, as practised in India, Borneo, and Africa.

"*India.*—The Hindoos appear to have carried on the direct process from time immemorial, as we may certainly infer from the large accumulations of slag which occur in various localities in India; and it is scarcely possible to imagine anything more rude than their appliances, or anything more diminutive than their scale of operation—it would seem that they have not made any substantial progress in their art, at least in many districts. Their furnaces are frequently not larger than a chimney pot, and hours of incessant toil are required to produce a few pounds weight of iron; and yet the price at which they sell the metal is surprisingly low. They belong to inferior castes, and their occupation is regarded as degrading.

"The ores employed are magnetic oxide and rich red and brown hæmatites.

"*Borneo.*—The natives of this remarkable and luxuriant island have long had the reputation of being skilful workers

in iron and steel. They practise the direct process, which they have carried on from time immemorial, and no tradition exists amongst them respecting the first introducer of the art. The following description is from 'Schwaner's Travels.'

"'Of all the south-eastern parts of Borneo, only the inhabitants of the district *Doeson Oeloe* understand the art of smelting iron and manufacturing it into sword-blades. Accordingly, iron is sent from this district into all parts of the country, and is preferred to English iron, experience having proved that sharper and more durable weapons may be produced from it than from irons of foreign manufacture. The ore employed is clay ironstone from beds of lignite, of which all the hills of the district are stated to be composed. The strata containing the ironstone are intersected by the river Barito, and are visible in its deep bed at low water. The natives avail themselves of this circumstance for procuring their supply of ore, which is more or less altered by the action of the water, and in composition approximates closely to brown iron ore.

"'The ore preparatory to smelting is interstratified with wood and roasted in heaps during one day, after which it is broken into pieces of the size of nuts and mixed with ten times its bulk of charcoal; and in this state it is charged. The furnace being two-thirds filled with charcoal, the mixture of ore and charcoal is added in sufficient quantity to form a conical heap above the mouth. The slag is tapped off at intervals of twenty minutes; and it is stated that during each tapping, which lasts five minutes, the blast is interrupted. Towards the close of the operation the blast is increased. The blast is produced by a blowing-machine consisting of a single-acting cylinder of wood, open at the top and closed at the bottom; it is made of the stem of a tree hollowed out. The blast is conveyed from the bottom of the cylinder through bamboo tubes to the twyers. The piston, of which the stroke

is four feet, is packed with fowl's feathers after the manner of the Chinese, and makes forty strokes per minute.

"'From this process a lump of iron is finally obtained weighing about 100 lbs.; it is taken out at the bottom of the furnace by means of wooden tongs, and removed to a place strewn over with fine slags, where it is worked with wooden mallets nearly into the shape of parallelopipedons. It retains much intermingled slag, and is divided into ten pieces, which are repeatedly made red hot and hammered out, until they are sufficiently purified and suitable for forging into sword-blades; they lose ⅓ in weight by this treatment.'

"*Africa.*—The natives of the interior of Africa seem to have attained considerable proficiency in the extraction and manufacture of iron by the direct process. The following interesting description of the process from personal observation was given by the celebrated but unfortunate traveller Mungo Park. I insert it without abridgment or alteration:—

"'The negroes on the coast, being cheaply supplied with iron from the European traders, never attempt the manufacturing of this article themselves; but in the inland parts the natives smelt this useful metal in such quantities as not only to supply themselves from it with all necessary weapons and instruments, but even to make it an article of commerce with some of the neighbouring states. During my stay at Kamalia, there was a smelting-furnace at a short distance from the hut where I lodged, and the owner and his workmen made no secret about the manner of conducting the operation, and readily allowed me to examine the furnace and assist them in breaking the ironstone. The furnace was a circular tower of clay, about ten feet high, and three feet in diameter, surrounded in two places with withes, to prevent the clay from cracking and falling to pieces by the violence of the heat. Round the lower part, on a level with the ground (but not so low as the bottom of the furnace, which was somewhat con-

cave), were made seven openings, into every one of which were placed three tubes of clay, and the openings again plastered up in such a manner that no air could enter the furnace but through the tubes, by the opening and shutting of which they regulated the fire. These tubes were formed by plastering a mixture of clay and grass round a smooth roller of wood, which, as soon as the clay began to harden, was withdrawn, and the tube left to dry in the sun. The ironstone which I saw was very heavy, of a dull red colour, with greyish specks; it was broken into pieces about the size of a hen's egg. A bundle of dry wood was first put into the furnace, and covered with a considerable quantity of charcoal, which was brought ready burnt from the woods. Over this was laid a stratum of ironstone, and then another of charcoal, and so on until the furnace was quite full. The fire was applied through one of the tubes, and blown for some time with bellows made of goat's skin. The operation went on very slowly at first, and it was some hours before the flame appeared above the furnace; but after this it burnt with great violence all the first night, and the people who attended it put in at times more charcoal. On the day following the fire was not so fierce, and on the second night some of the tubes were withdrawn and the air allowed to have freer access to the furnace, but the heat was still very great, and a bluish flame arose some feet above the top of the furnace. On the third day from the commencement of the operation all the tubes were taken out, the ends of many of them being vitrified with the heat, but the metal was not removed until some days afterwards, when the whole was perfectly cool. Part of the furnace was then taken down, and the iron appeared in the form of a large irregular mass, with pieces of charcoal adhering to it. It was sonorous, and when any portion was broken off, the fracture exhibited a granulated appearance like broken steel. The owner informed me that

many parts of this cake were useless; but still there was good iron enough to repay him for his trouble. This iron, or rather steel, is formed into various instruments by being repeatedly heated in a forge, the heat of which is urged by a pair of double bellows of a very simple construction, being made of two goat-skins, the tubes from which unite before they enter the forge, and supply a constant and very regular blast. The hammer, forceps, and anvil, are all very simple, and the workmanship (particularly in the formation of knives and spears) is not destitute of merit. The iron, indeed, is hard and brittle, and requires much labour before it can be made to answer the purpose."

Notwithstanding the importance of efficiently preparing the ores preparatory to smelting, there are but few machines for that purpose worth notice. Amongst these may be enumerated Hunt's Patent Separator, and Edward's Patent ore-dressing machine. In the former, which may be considered as an improvement upon the old hand-jig, the ore is fed upon a sieve from a hopper, and water is forced through the sieve in pulsations by a wooden cylinder and piston worked by means of a lever by a workman, who, when the separation is effected, removes the waste and ore by a hand scraper. In Edward's machine (Fig. 1), which is very economical of labour, the ore is fed in the same way as in Hunt's; but the separation is effected by pulsations given to the water with which the machine is filled, by means of a set of revolving cams striking upon a flexible disc of leather or other material, which is again slowly raised by the pressure of the water in the tank of the machine. The waste in working ores is removed as it rises to the surface of the sieve, by a set of self-acting scrapers. In the case of coal, it is of course the coal that is removed, whilst the shale and peritiferous portions collect on the sieve. The loss in washing coal is said to be trifling. By this mechanical arrangement one workman is capable of attending several

machines, any number of which can be readily worked together by steam or other available power.

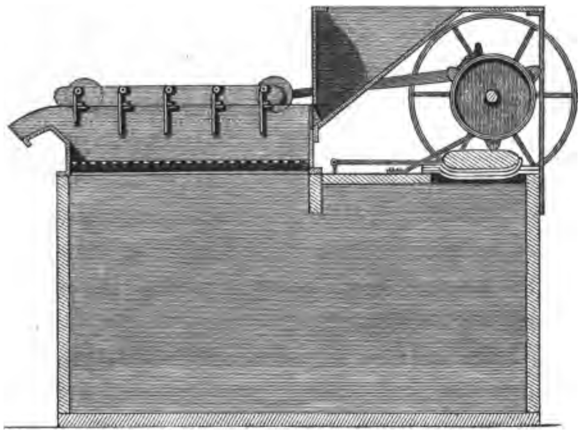

Fig. 1.

Process with the Catalan Hearth.—This process derives its name from the province of Catalonia, in the north of Spain, where, probably, it was first introduced into Western Europe. Until a recent period it was extensively practised in the south of France, especially in the department of Ariége, which is separated from Catalonia by the Pyrenees. Historical documents exist, which prove that the direct process of extracting iron was practised in the French Pyrenees so long ago as 1293, and has been ever since in operation. But it is probable that it was established in the same locality long anterior even to that remote period. Originally it appears to have been conducted on a very small scale, like that of the native Hindoo iron-smelters of the present day.

The character of the iron produced by this process is worthy of notice. It is described by François as in general fibrous, hard, very malleable, and particularly tenacious, but deficient in homogeneity. Its body is more or less charged with spots and grains of steel, which render it difficult to file

or hammer. Moreover, owing to imperfect extrusion of the slag, it is apt to be unsound and deficient in malleability.

The first and older process is uncertain in its results, involves considerable expense, and, as there are no efficient means of getting rid of the earthy impurities, necessitates the employment of rich magnetic, specular, or hæmatite, ores; on account of these defects, it is now seldom employed. The ores to be reduced by this process were heated with charcoal in open furnaces like the Catalan hearth, the fire being urged by a blast. The oxygen combined with the carbon, and the water and volatile substances were driven off, and the iron—carburized and partially fused—sank to the bottom of the hearth. If the process were stopped at this point, an imperfect cast-iron or steel was the result. But usually the blast was then directed downwards, so as to play over the surface of the iron, and oxidize the greater part of the combined carbon; during this operation the iron became tough and malleable, and fit for the hammer.

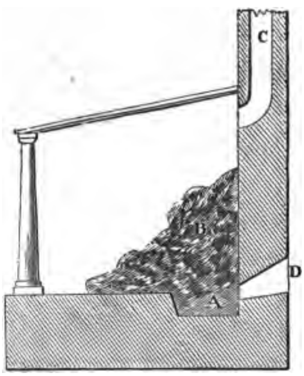

Fig. 2.

The annexed section (Fig. 2) shows the disposition of the Catalan hearth during the process of reduction. The fuel and ore B are piled over the hearth A, and ignited; the blast to urge the fire is applied at D, and the gaseous products of combustion pass off by the chimney C.

The process has been employed in America, where capital was wanting for the erection of blast-furnaces, but it is very wasteful, as is shown by the following statement of the materials employed:—3 tons of rich ore produce 1 ton of iron; 5 hours are necessary to convert a loup of iron weighing only 150 lbs.

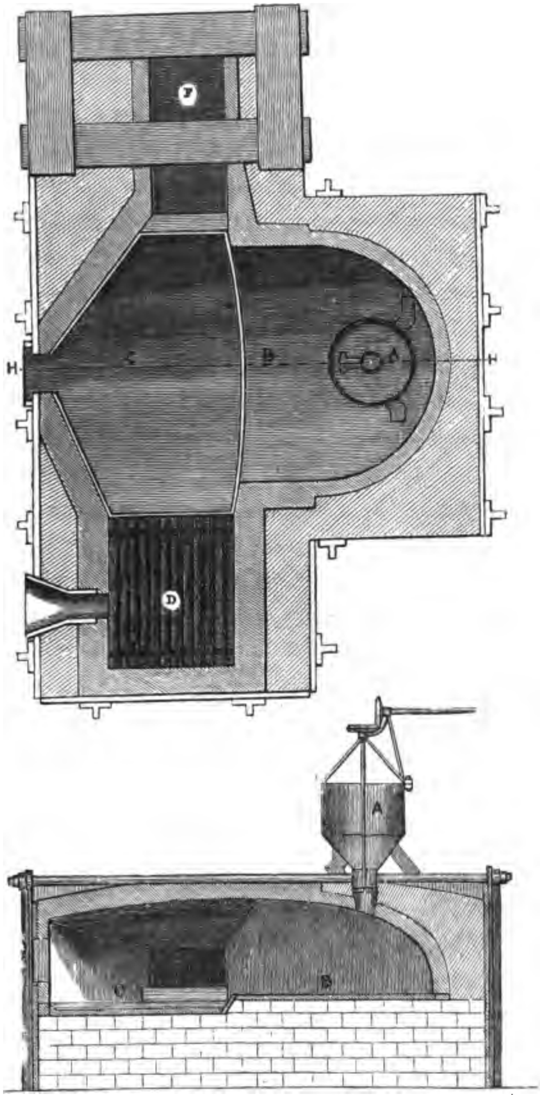

Fig. 3.

Mr. Clay's Process.—A similar process has lately been invented by Mr. Clay, which appears to reduce the rich ores

with great advantage, and to be free from the defects of the older process. Mr. Clay mixes the ore with four-tenths of its weight of coal, and grinds it so small that it will pass through a screen of one-eighth of an inch mesh; it is then put into the hopper A (Fig. 3), from which it falls upon the preparatory bed B, at the side of the puddling furnace C. While in this position, the ore is heated, and partly decomposed, and the coal coked. The charge is then drawn forward into the reverberatory furnace C, where it is fused by the heat of the gaseous products passing from a fire at D to the chimney F, and is puddled and balled in the ordinary way. The cinder produced contains 50 to 55 per cent of iron, is free from phosphorus, and is very suitable for smelting in the blast-furnace. This process is said to produce puddled bars equal to those made by the four operations of calcining, smelting, refining, and puddling, under the old system, and appears to be peculiarly adapted for the reduction of those rich ores which cannot be smelted advantageously in the blast-furnace, because the small quantity of slag which is formed does not protect the metal from the oxidizing effects of the blast.

We need not add that Mr. Clay's procees has proved a failure; it is now abandoned in places where it was formerly employed, and is no longer in use.

Mr. Renton in 1851 patented a process for making wrought iron directly from the ore. This process has since been abandoned.

In 1855 Mr. Chenot obtained one of the "Grandes Medailles d'Or," for an invention whereby the ore was reduced to metallic sponges without smelting, and these sponges were produced by the direct reduction of brown hæmatite by cementation in charcoal. This process has also been superseded.

A few years ago Mr. Yates took out a patent in which he proposes to extract iron directly from the ores. This he

effects by the exclusive use of gas furnaces, in which carbonic oxide is produced in generators. This process, although known for some years, still remains in abeyance, and will probably share the fate of its predecessors.

Smelting.—The process of smelting in the blast-furnace is now almost universally adopted for the reduction of iron ores; and for the cheapness and working qualities of the metal produced, as well as for the rapidity of the manufacture, it is decidedly superior to all others.

Calcination of the Ores.—Ores which contain much carbonic acid, water, or volatile matter, were at one time invariably subjected to a preparatory process of calcination; but since the introduction of the hot-blast they are now frequently employed in the raw state. The calcination is sometimes effected in the open air, by stacking the ore with coal, setting fire to it, and allowing it to burn out; but this method is liable to serious objection. It is impossible to keep the temperature uniform throughout the heap; and, in consequence, while some portions are scarcely affected, others are fused together into large masses, which cannot be smelted without difficulty, even when broken up. Apart from the irregularity and uncertainty of the open-air process, it appears to be more expensive than the calcination in kilns, when the admission of air is entirely under command. These ovens or kilns are usually built of masonry, and are placed, if possible, on a level with the charging platform of the smelting furnace. These kilns are so arranged that the process is continuous, the calcined ore being withdrawn below whilst the process is going on above. The argillaceous ores lose, during this process, 20 to 30 per cent; the carbonaceous, 30 to 40 per cent of their weight. In Scotland, the blackband and clay ironstone ores are all calcined, even for the hot-blast, the coaly matter in the blackbands being almost sufficient to effect the calcination without other fuel. The carbonaceous ores

lose as much as 40 or 50 per cent of their weight in this process.

The High Cold-blast Furnace.—The blast-furnace consists of a large mass of masonry, usually square at the base, from which the sides are carried up in a slightly slanting direction, so as to form, externally, a truncated pyramid. In the sides there are large arched recesses, in which are the openings into the furnace for the admission of the blast, and for running out metal and the cinder; at the top of the furnace is a cylindrical erection of brick-work, called the tunnel-head, for protecting the workmen from the heated gases rising from the furnace, and having one or more doors, through which the charges of ore, fuel, and flux are thrown into the furnace. In front, protected by a roof, is the casting-house, where the metal is run from the furnace into moulds.

Fig. 4 is a vertical section, and Fig. 5 a plan, of one of the furnaces at the Dowlais Ironworks, which belong to the representatives of the late Sir J. Guest. Mr. Truran, in a recently published and elaborate work on iron, has figured and described it. He states that it is one of the largest class, 38 feet square at the base, diminishing upwards 3 inches for every vertical foot, till it attains a height of 25 feet, where the square form ends with a moulded cap; above this, the form is circular, diminishing in diameter at a similar rate, and finishing at top with a plain moulded cornice, as a support for the charging platform. In the section and plan A is the hearth, 8 feet high and 8 feet in diameter; BB the boshes, rising to a height of 15 feet, and 18 feet wide at their greatest diameter. From the top of the boshes the body of the furnace contracts, in a barrel-shaped curve, so that at the charging platform D, at a height of 50 feet, it is only 10 feet in diameter; E is the tunnel-head, with doors of iron, to admit the charges of ore and fuel; FFF the tuyere-houses, arched over and spread outwards, with the openings into the furnace for

admitting the blast. G, the opening through which the iron is run from the furnace. The exterior is generally built of stone, and requires to be strongly bound with iron hoops, to prevent fracture from the expansion of the interior by the heat.

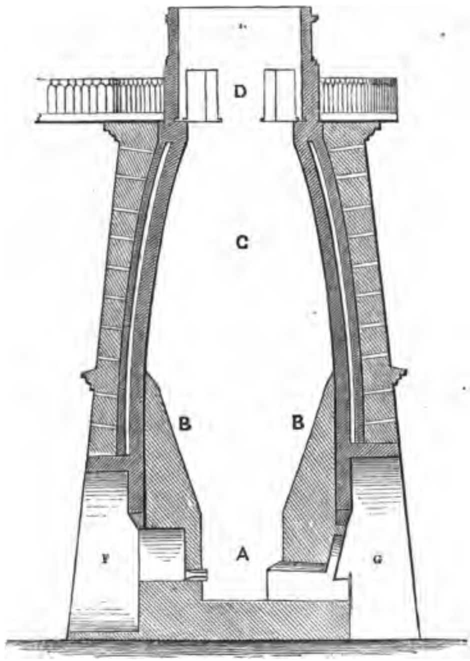

Fig. 4.

The interior is lined with fire-brick set in fire-clay, a space of two or three inches being left between the two courses, to allow the expansion of the inner course. The hearth and boshes were usually constructed of refractory sandstone grit, or conglomerate, but fire-bricks are now chiefly used; and, although they do not last so long, they are in the end more economical, and may be replaced whenever the furnace is blown out. The proper inclination of the boshes is a point of much importance, so that the materials, whilst smelting, may neither press too heavily downwards, nor yet be so retarded

as to adhere in a half-liquid state to the brick-work, and cool there, thus forming what are known by the name of *scaffolds*, the removal of which is a source of great inconvenience.

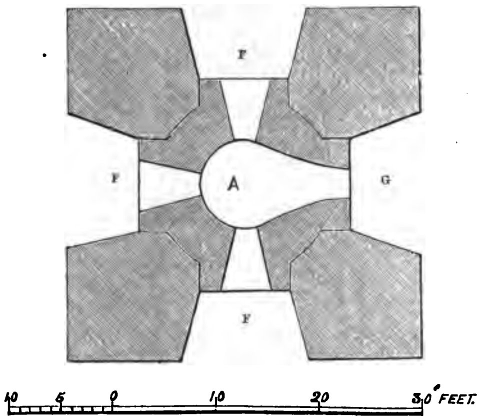

Fig. 5.

The Cupola Furnace.—Another form of furnace is occasionally used for smelting, called the cupola, and built much more slightly than the blast-furnace. Its form is circular, and from the boshes upwards it is constructed of fire-brick, one, or sometimes two courses in thickness. It is strongly bound together with wrought-iron hoops; and pillars of cast-iron, bolted at each end to imbedded rings of the same metal, rise through the foundation to the summit of the tuyere arches, giving considerable firmness and stability to the structure. Cheapness and facility of construction are much in its favour; and although objections have been made to the thinness of its sides, as permitting great loss of heat by radiation, it has met with very general adoption.

In addition to the cupola furnace, another of the same character has of late years been introduced. In consists of a truncated cone, composed entirely of boiler-plates rivetted together, as per annexed Fig. 6. On the four opposite sides,

recesses are cut to admit the tuyeres and the opening from the hearth into the casting-house. The interior of the furnace is lined with fire-brick and fire-clay in the usual way, and

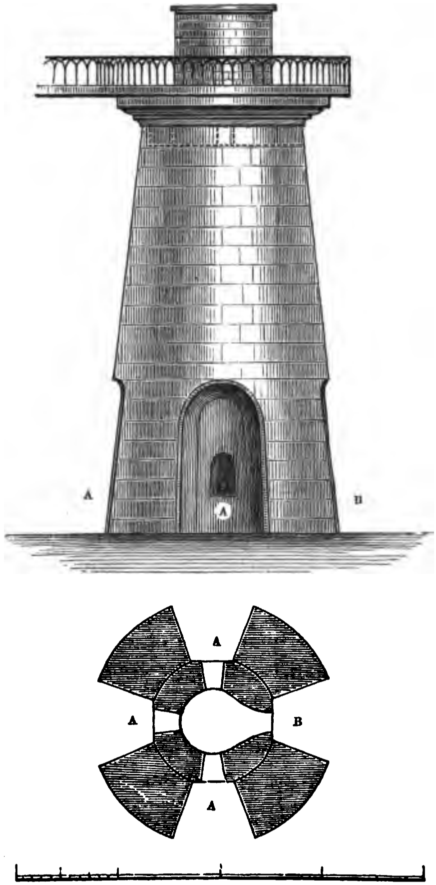

Fig. 6.

this plate furnace is not only perfectly secure, as regards the expansion and contraction, but it is found to be economical and to answer every purpose in common with the large stone and iron-bound furnaces.

Fig. 6 exhibits a plan and elevation of this description of furnace, the parts AAA being the tuyere-houses, and B the opening for the discharge of the metal from the furnace.

The Blast.—The blast is usually created by a steam-engine; a piston being attached to the extremity of the beam, working in a cylinder of large diameter, and forcing the air through proper valves into a large spherical or cylindrical reservoir, constructed of boiler-plate, whence its own elasticity causes it to flow in a regular, unintermitting stream into the furnace. A cylindrical vessel, open at bottom, and immersed in a pit of water, has sometimes been used to regulate the pressure of the blast; but the water evaporated is detrimental to the working of the furnace. The nozzles by which the blast is directed into the furnace are made of cast or wrought iron, and sometimes a current of water is conveyed round their extremities to keep them cool. The number of blowpipe nozzles to each furnace varies at different works; the usual number is three, one for each of the tuyere-houses; but sometimes six, eight, or twelve are employed, as shown in Fig. 20; it however appears questionable whether this is not objectionable, as the density and penetrating power of the blast is considerably diminished by this system of diffusion. This, however, is a point which can only be decided by practice, and must be left to the judgment of the smelter. The usual pressure of the blast as it enters the furnace is about 3 lbs. per square inch, but in some cases it is as much as 5 lbs. per square inch.

The Scotch iron-smelters allege that the diffusive power of the blast is increased rather than diminished by increasing the number of blowpipe nozzles, and give as a reason for the use of six or more, that they can be so much more easily repaired, the stoppage of one not materially affecting the working of the furnace.

The dimensions and form of the blast-furnace vary greatly,

according to the fashion of the district, and the notions of the builder. Yet so much does the quantity and quality of the iron depend upon the size of the furnace and strength of the blast, that we may venture to assert that the production varies in the ratio of the cubical contents of the furnace, and the volume of air admitted. Mr. Truran gives the following particulars of the Dowlais Foundry iron furnace:—"The capacity is 275 cubic yards. It is blown with a blast of 5390 cubic feet of [cold] air per minute. The materials charged at the top consist of calcined argillaceous ore, coal, and limestone. The yield or consumption averages 48 cwts. of calcined ore, 50 cwts. of coal, and 17 cwts. of broken limestone, to 20 cwts. of crude iron obtained. The weekly make of iron is occasionally over 130 tons. The weekly product of cinder amounts to 250 tons. For the production of white iron for the forge, in furnaces of the same capacity as the foregoing, a larger volume of blast is employed, along with a different burden of materials. The blast averages 7370 feet per minute. The consumption of materials to one ton of iron averages 28 cwts. of calcined argillaceous ore, 10 cwts. of hæmatite, 10 cwts. of forge and finery cinders, 42 cwts. of coal, and 14 cwts. of limestone. With these materials the weekly produce amounts to 170 tons of crude iron, and 310 tons of cinder."

Action within the Blast-Furnace.—The action which takes place in the blast-furnace is as follows:—The contents, being raised to an intense heat by the combustion of the fuel, are brought into a softened state; the limestone parts with its carbonic acid, and combining with the earthy ingredients of the ironstone, forms, with them, a liquid slag, whilst the separated metallic particles, descending slowly through the furnace, are deoxidised and fused. In their passage they combine with a portion of carbon, and at last settle down in the hearth, from whence they are run off into pigs about every twelve hours; the slag, being lighter, floats upon the surface of the liquid

metal, and is constantly flowing out over a notch in the dam-plate, level with the top of the hearth. This slag indicates, by its appearance, the manner in which the furnace is working. Thus, if the cinder is liquid, nearly transparent, or of a light greyish colour, and has a fracture like limestone, a favourable state of the furnace is indicated. Tints of blue, yellow, or green are caused by a portion of oxide of iron passing into the slag, and show that the furnace is working cold. The worst appearance of the cinder is, however, a deep brown or black colour, the slag flowing in a broad hot rugged stream, and indicating that the supply of coke is not sufficient to deoxidise the whole of the iron.

During the process of smelting, the interior of the furnace requires to be very carefully watched. The stream of air constantly rushing in at the tuyeres, exerts a chilling agency on the melted matter directly opposed to it at its entrance. The consequence of this is the formation of rude perforated cones of indurated scoriæ, stretching from either side horizontally into the furnace, each one having its base directly over the embouchure of a blast-pipe. When these project only to a certain extent, they are favourable to the working of the furnace, as the blast is thrown right into the centre, and prevented from passing up the sides and burning the brick-work. Sometimes, however, when the furnace is driving cold and slow, these conduits of slag become so strong, and jut out so far as to meet in the middle, and thus cause a great obstruction to the entrance and ascent of the blast. When this happens, there is usually no remedy but to increase the burden—that is, to increase the quantity of *mine* or ore to the charge. This causes an intense heat; the furnace is said to work hot, and the conduits of slag drop off from the sides. This, however, is followed by bad as well as good consequences: the brickwork is frequently melted, and, for a time, the iron produced is small in quantity, and of the worst

quality. To bring the furnace again to its proper state, the burden must be reduced; the sides then become cool, new tubes of slag are formed, and the iron produced is good. These slags are imperfectly vitrified silicates, the composition of which was found by Berthier to be, in the case of a specimen from Merthyr Tydvil—

Silica	40·4
Lime	38·4
Magnesia	5·2
Alumina	11·2
Oxide of iron	3·8
Sulphur	traces
	99·0

At the end of every twelve hours, more or less, the furnace is tapped; that is to say, the aperture in the dam-stone, which, at the commencement, had been stopped up with a mixture of loam and sand, is re-opened, and the metal contained in the hearth allowed to flow out into moulds, made in the sand of the cast-house floor, thus forming a cast or sough of pigs. When this operation ceases, the dam-stone is again secured, and the work proceeds as before. In this manner a furnace is kept continually going, night and day, and never ceases to work until repairs are necessary. Incessant action has even been thought necessary to the successful carrying on of iron-works; but the example of perhaps the largest ironmaster in South Wales has shown, contrary to general practice in that district, that smelting may be discontinued for at least one day in the week without any very serious derangement of operations.

Elevation of Materials to the Tunnel-head.—The communication between the ground and the tunnel-head is effected in various ways. In South Wales the furnaces are usually built on a declivity, which affords ready means of access from behind, the furnace being charged by wheeling the materials

on a level platform extending from the higher ground to the tunnel-head of the furnace. Where this is not possible, an inclined plane has been used, with two lines of railway worked by a steam-engine, the trucks being connected so as to balance one another. The pneumatic lift has also been employed, consisting of a cast-iron cylinder inverted in a well of water, and balanced like a gasometer, so that it could move upwards or downwards in a vertical direction. A pipe from the blowing-engine is introduced under the cylinder; so that the materials being wheeled upon the top, and the blast turned into it, the pressure of the air at once raises it, with its load, to the level of the charging platform.

Thus far we have confined our observations to the production of iron by the cold-blast process; we have now to consider the changes introduced by the employment of a heated blast.

The Hot-blast Process.—In the year 1828, Mr. J. Beaumont Neilson, a practical engineer at Glasgow, took out a patent for an "improved application of air to produce heat in fires, forges, and furnaces, where bellows or other blowing apparatus are required." Mr. Neilson proposed to pass the current of air through suitably shaped vessels, where it was to be heated *before it entered the furnace.* In this simple substitution of a hot-blast heated in a separate apparatus, for a cold-blast heated in the furnace itself, consists the whole invention.

Like most other improvements the progress of this was at first slow. Retarded by practical difficulties, which beset all new processes in their first use—stopped every now and then by the prejudices of custom and ignorance, which cling with inveterate tenacity to maxims of established practice, and repel indiscriminately innovations which improve and those which modify without improving—the invention was more than once on the point of being abandoned. A great part of the interest in its possible remuneration was transferred by

the inventor to strangers, whose combined efforts and influence were necessary to insure its success. But though thus tardy in its first steps and feeble in its early efforts, the hot-blast process is now adopted at the greater number of the iron-works of Great Britain, and other parts of Europe, and America.

It is perhaps not generally known that practical men, previous to Mr. Neilson's invention, universally believed that the colder the blast the better was the quality and quantity of the iron produced; and this opinion appeared to be confirmed by the fact that the furnaces worked better in winter than in summer. Acting on such views, the ironmaster actually in some cases resorted to artificial means of refrigeration, to reduce the temperature of the blast before it entered the furnace. The fact of the improved action of the furnace in winter may perhaps be explained as a consequence of the diminished amount of aqueous vapour contained in the atmosphere in cold weather; and the opinion that the low temperature is the cause of the alleged increase of production has been shown to be wrong by the success of Mr. Neilson's invention.

This simple invention affects only the transit of the air from the blowing cylinder to the furnace, an oven or stove being interposed, through which, in appropriately shaped vessels, the air is conducted, and in which it is heated to 600° or 800° Fahr., or to any other temperature adapted for the purpose of smelting.

Mr. Neilson's earliest hot-blast oven for smelting purposes consisted of a wrought-iron chamber about 4¼ feet long by 3 feet high and 2 feet wide, set in brickwork like a steam-boiler. This was then replaced by a cast-iron retort, similar to that shown in Fig. 7.

In an oven of brickwork O O O O, with a fire fed by the door D, a large cylindrical tube or receiver *h h*, about 3 feet in

diameter, and 8 or 10 feet long, was placed. The pipes B and S, attached to the receiver *h h* at the opposite ends, communicated with the blowing-cylinder and smelting-furnace respectively. Lunular-shaped partitions *p p p*, projecting from

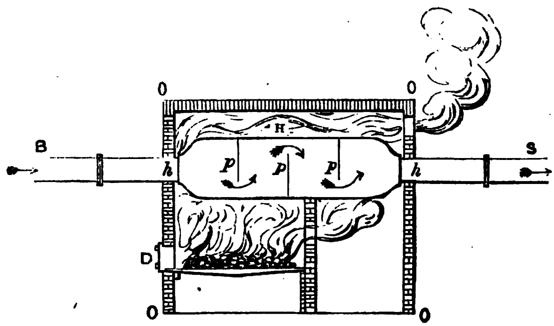

Fig. 7.

opposite sides on the interior of the receiver, caused the air passing through it to impinge alternately first on one side and then on the other, in order that the temperature might be uniformly and effectively communicated from the metal to the blast. By this means a moderate current of air has been heated up to 300° or 400° Fahr.

Long ranges of tubes, variously designed, were then introduced to increase the heating surface as much as possible, and it was with this arrangement that a temperature of 600° Fahr. was first attained.

Calder Heating Apparatus.—Figs. 8, 9, 10, and 11, show the apparatus first employed, we believe, by Mr. Dixon at Calder, and hence generally called the Calder pipes. As erected at the Butterley Ironworks, Derbyshire, the apparatus consists of two parallel horizontal pipes, L L, Fig. 8, called technically the "lying pipes," one communicating with the cold-blast inlet pipe B, the other with the hot-blast outlet pipe S, Figs. 10 and 11. Into sockets formed in these, the ends of the arched heating pipes *h h h* fit tightly, as shown in Fig. 8,

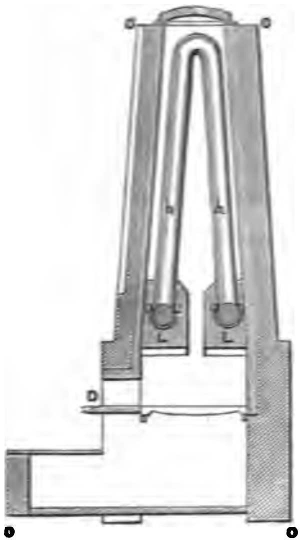

Fig. 8. End Elevation.

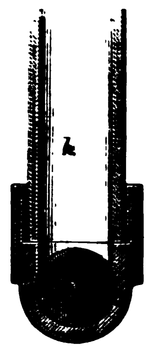

Fig. 9. Joint of Heating Pipe in Lying Pipe.

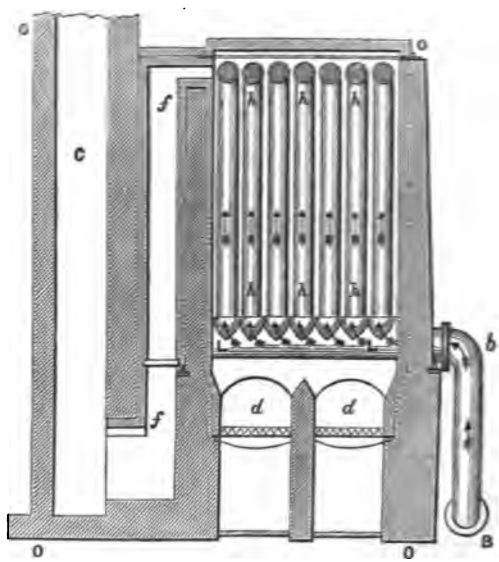

Fig. 10. Elevation.

and in Fig. 9 upon a larger scale. The air, therefore, entering the inlet pipe B, Figs. 10 and 11, passes over the transverse arched pipes *h h*, where it is exposed to the action of a large surface of heated metal, and is delivered into the hot-blast pipe S, which conveys it at the required temperature into the blast-furnace. The whole apparatus is enclosed in the oven or furnace O O O O, as shown in the Figs. 8, 10, and 11.

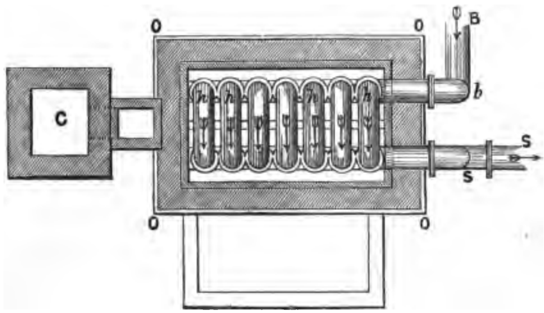

Fig. 11. Plan.

The figures of the transverse pipes vary considerably at different ironworks. Sometimes they rise up and form a large semicircular arch over the fire, 8 or 10 feet perpendicularly, and are then connected by an arch at the top; sometimes they cross the fire in the form of a pointed arch, variously acuminate, or a single large tube is used, traversing the furnace in a long spiral direction. Their cross-section is as various as the form in which they are bent; pipes of circular, flattened elliptical, rectangular, heart-shaped, and other sectional forms have been employed, in order to increase the heating surface in proportion to the volume of the blast. All these forms of apparatus, although admirably adapted for heating the air, are liable to fracture and leakage, from the unequal expansion of the metal.

One other form of apparatus, represented in the following figures, Nos. 12, 13, and 14, demands notice, on account of its great heating power. The cold air enters by the pipe M

into one side of the lying pipe A A, which is divided down the centre by a partition or diaphragm, and then passes up

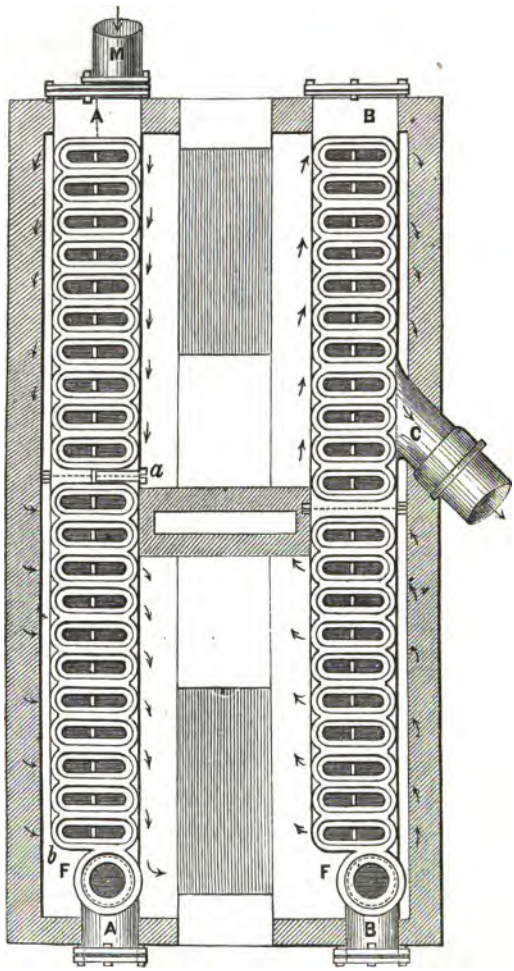

Fig. 12.

one side of the heating pipes, which are also divided by partitions; it then turns round at the top, as shown at D (Fig. 13), and descends in the direction of the arrows into the lying pipe A A on the other side to that which it entered.

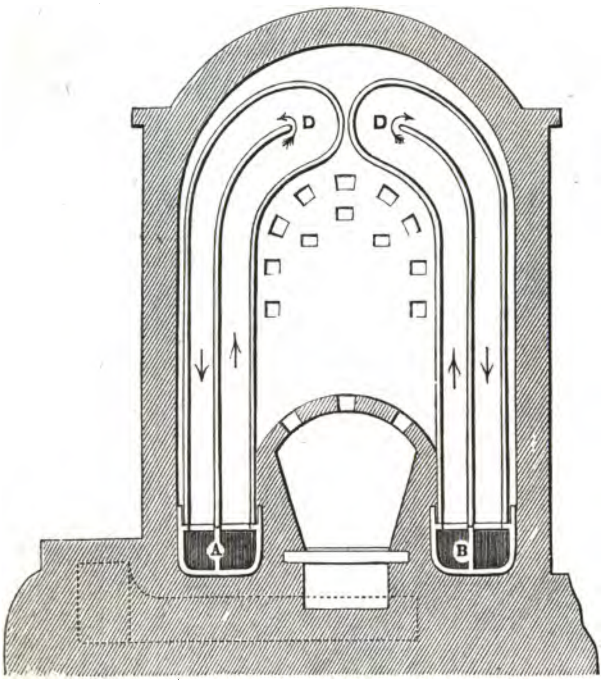

Fig. 13.

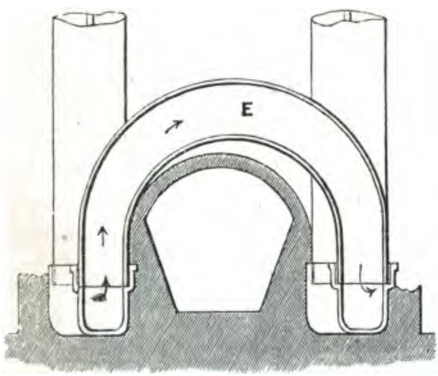

Fig. 14.

It is thence conveyed by the arched pipe E (Fig. 14) into the second divided pipe B B, through another series of heating pipes, and ultimately escapes by the outlet pipe C, at a high

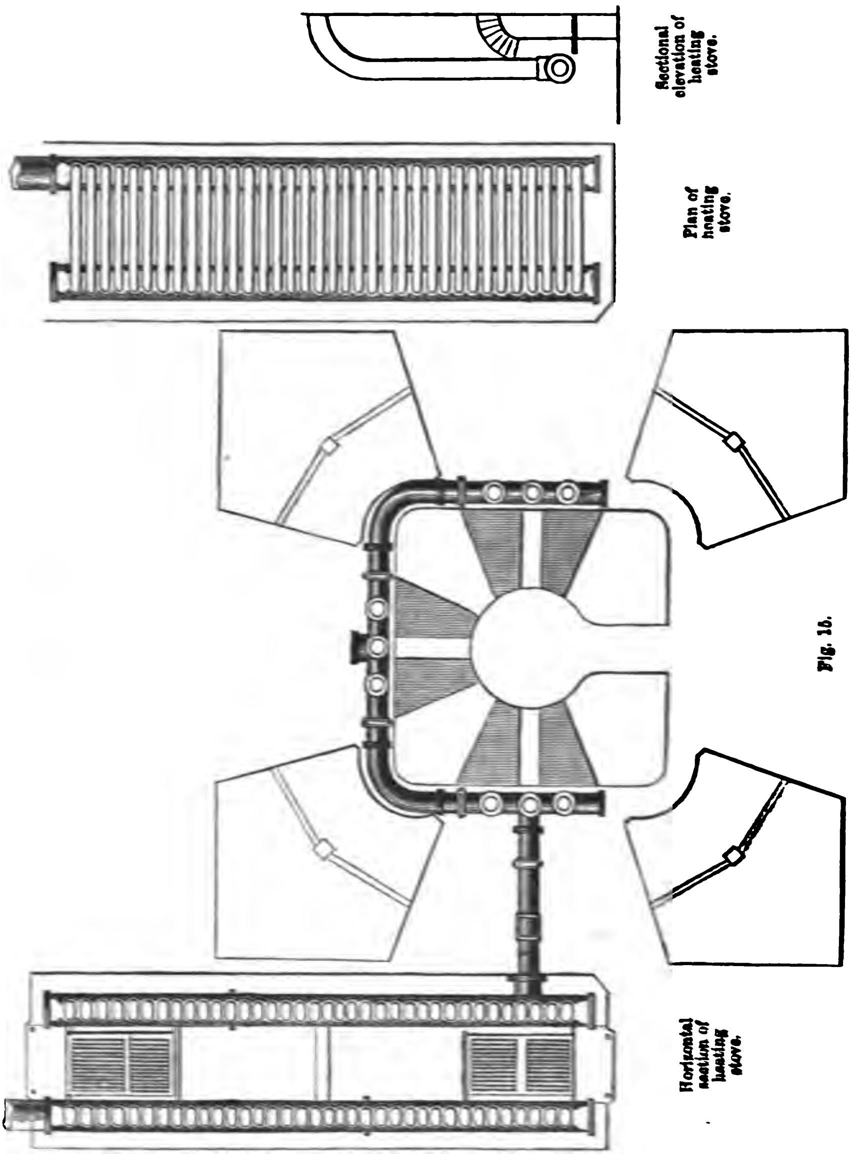

Fig. 15.

Plan of Coltness Blast-Furnace and Heating-Stoves (p. 72).

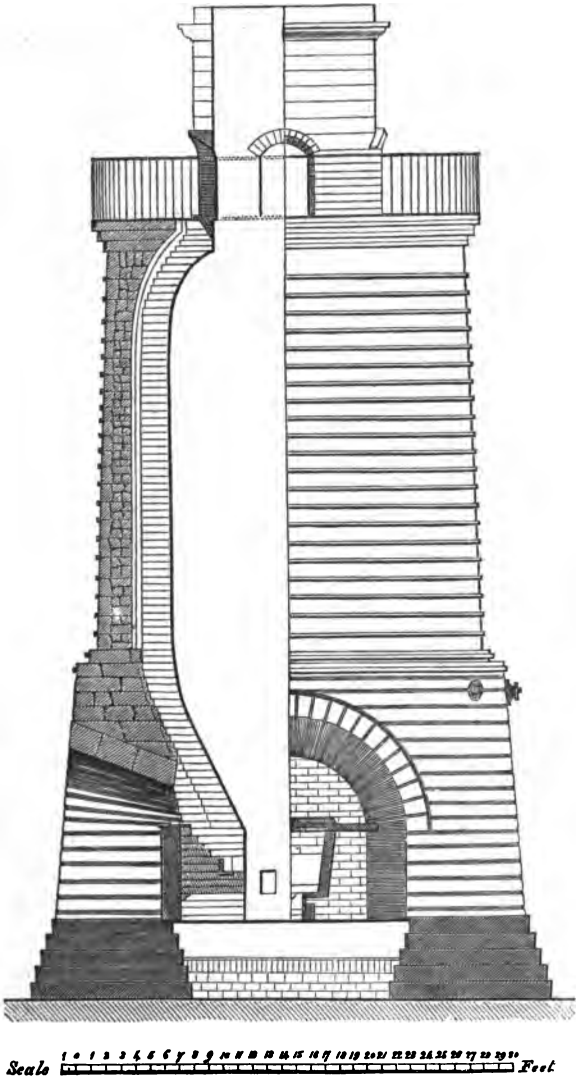

Fig. 16. Sectional Elevation of Coltness Furnace.

temperature, to the smelting-furnace. The diaphragm pipes are, however, not generally used.

The best arrangement is exhibited in the drawing of one of the furnaces and heating apparatus of the Coltness Works, kindly furnished by Mr. Hunter, the intelligent managing partner of that establishment. The drawings (Figs. 15 and 16) represent a sectional elevation and plan of a very successful and regular working hot-blast furnace; but the size and form, as already observed, require to be governed by the quality and nature of the materials that are to be used.

To obviate the tendency to fracture of the iron tubes at the crown of the arch, from the expansion of the metal, due to the very high temperatures to which it is subjected, only one lying tube is made fast in some cases, and the other placed upon rollers to give as much freedom as possible for the motion of the pipes and the reduction of the strain.

The following dimensions of the West Staffordshire ovens have been given by Mr. Martin of Wolverhampton :—

Length inside casing . . .	16 feet.
Breadth	7½ „
Number of siphon pipes . . .	16 „
Effective area of heating surface . .	700 sq. ft.
Total area of fire grate . . .	35 „

—an oven of these dimensions being capable of heating the blast for four tuyeres to a temperature of 600° or 700° Fahr.

The latest improvement of the hot-blast oven has been the introduction of round ovens. The following example (Fig. 17) is taken from a series described by Mr. Marten, as constructed under his directions in 1857. In this, two *circular* main lying pipes are used, and the siphon pipes are arranged upon them in a circle, as shown in Fig. 17. A large brick core is introduced, which increases the reverberatory action on the pipes, and maintains the temperature more uniform. The area of the fire-grate in this oven is 38 square feet, and the area of direct heating surface in the pipes 850 square feet. It is capable of heating the blast for three tuyeres to 800° Fahr. In this furnace the horizontal expansion takes place almost

entirely in the lying pipes, and has no effect in fracturing the siphons, so that the leakage and danger of fracture is reduced to a minimum.

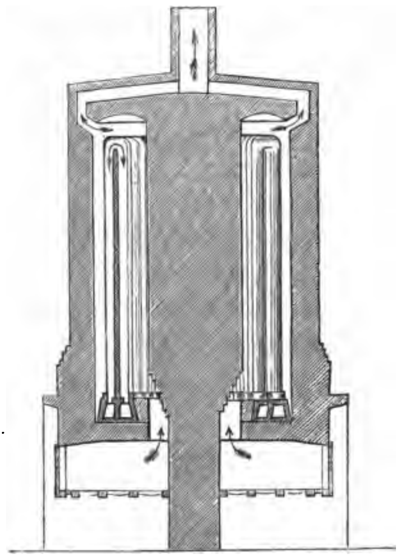

Fig. 17.

In regard to the consumption of fuel in these ovens, it is sometimes as much as 9 cwts., and at others as low as 5 cwts. per ton of iron produced in the blast-furnace.

Another hot-blast stove, which has recently been employed at Messrs. Cochrane's works at Ormesby, near Middlesborough, has been described by Mr. Cowper to the Institute of Mechanical Engineers. In this case a pair of stoves is used, the blast being turned alternately at intervals of an hour or two hours through each. They consist of brickwork chambers filled loosely with fire-brick or other refractory substance, and heated from the bottom by coal fires. The products of combustion pass upwards through the brickwork, heating it in passing till they emerge at the top and pass away to the chimney at a comparatively low temperature. After the

chamber is thoroughly heated, the fire is shut off and the cold blast passed in, so that, passing downwards from the colder to the hotter part, it reabsorbs the heat imparted to the fire-bricks. Meanwhile the other stove is being heated in a similar way; and after two hours' work, more or less, according to the size of the stoves, the blast is turned into the second stove, and the products of combustion allowed to reheat the first.

The only means we possess at present of the working of these stoves will be found in Mr. Cowper's paper. The following abstract gives the most interesting facts elicited during two months' working of a pair of these stoves, supplying a single tuyere with 1000 cubic feet of air per minute :—

Cubic contents of fire-brick in stove .	250 feet.
Heat of escaping gaseous products in chimney	150° to 250°
Temperature of blast after passing through the regenerative stove . .	1300°
Variation in the temperature of the blast during two hours' work . .	100° to 150°
Outside diameter of stoves . .	7 feet 6 inches.

The prospective advantages of these regenerative stoves are greater economy from the use of cheap fire-brick surfaces instead of the costly iron pipes, which are so apt to cause leakage at the joints and to deteriorate in use; and the higher temperature attainable by the blast, owing to the fact that the heat is received direct from the surfaces heated, instead of being conducted through a thick metal casing.

The more difficult the reduction of the ironstone the smaller must be the diameter of the hearth, so as to enable the blast to penetrate and circulate throughout the whole of its contents. In other conditions, where the ores are easily reduced, hearths of 9 feet diameter have been introduced with great advantage, and that without detriment to the quality of the iron produced. The diameter of the body of the furnace

is likewise regulated by the quality of the materials used, and in cases where the coal is culm or anthracite, and the ore hard, a large diameter is found to work very irregularly; and the results have been, where furnaces have been erected 18 feet in diameter, to have them reduced to only 9 feet.

The height of the furnace is also regulated by the nature of the materials and the strength of the blast by which they are reduced. Sometimes, when the coal is soft, and crushes by the superincumbent pressure, it is bound or compressed to such an extent as to prevent the blast penetrating the mass, and causes an irregular working of the furnace; and, moreover, under these conditions, it makes what is called white or silvery iron.

The pressure of the blast requires also to be regulated to suit the materials, and, according to the workings at Coltness (shown in Figs. 15 and 16), the pressure is about 4 lbs. on the square inch, and as much as 10,000 cubic feet of air is discharged into the furnace per minute. The temperature of the blast is 600° Fahr., and the area of the heating surface of the apparatus for raising that temperature is 3500 square feet.

The quantity of materials to make a ton of iron at these works varies in some relative proportion to their densities; but the following may be taken as a fair average of the consumption of fuel, ore, limestone, etc.—

	Ton.	cwts.
Of raw coal . . .	1	10
Of calcined ironstone . .	1	17
Of broken limestone . .	0	12
Of coal for heaters . . .	0	4
Of coal for blowing engine . .	0	4

With the above charges the furnaces will produce from 168 to 170 tons per week, or 8700 tons of good iron per annum.

The usual proportion of materials for the smelting-furnace is, in Staffordshire, with the argillaceous ores, 3 tons of coal and 15 or 18 cwts. of limestone to 1 ton of iron produced, the blast being heated to about 600°, and introduced under a

pressure of 2½ to 3½ lbs. per square inch; 2 to 3 tons of ores are needed to make 1 ton of iron, according to the richness of the ironstone. If we compare this with the Yorkshire cold-blast works, using coal and smelting similar ores, we find that, on the average, 4 tons of coal and 20 cwts. of limestone are required to produce 1 ton of iron, the amount of ironstone needed being 3½ tons. If, in this latter case, coke is used, the amount of fuel needed, however, is only 2½ to 3 tons, and 11 to 17 cwts. of limestone.

In South Wales, at the anthracite furnaces, where, of course, hot-blast is employed, the burden is about 3 tons 7 cwts. of argillaceous carbonate, 1 ton 15 or 1 ton 17 cwts. of anthracite, and 17 cwts. of limestone, to 1 ton of iron produced.

In Scotland, with blackband ores, about 1 ton 16 cwts. of calcined ironstone is used to 2½ tons of coal and 10 cwts. of limestone to produce one ton of iron, inclusive of the fuel needed for the hot-blast ovens and blowing engine.

Hot-blast Furnace.—Figs. 18, 19, and 20 show the general arrangement and the disposition of a hot-blast furnace, and the apparatus connected with it. J is the blowing cylinder, from which the air is forced into the receiver K, made of wrought-iron boiler plate; from this it passes by the pipe L into the heating-ovens, one of which is shown in section at M, and the pipe N conducts it, when heated, to the furnace. PPP are the tuyeres, FF the charging-doors, E the tunnel-head.

With regard to the advantages and defects of the hot-blast process, much has been said on both sides, and the question does not appear by any means exactly settled. It is asserted, on the one hand, that iron reduced by the hot-blast loses much of its strength, whilst, on the other, it is contended that the quality of the iron is richer, more fluid, and better adapted for general purposes than that produced by the cold-blast. The advocates of the hot-blast say that the process has in-

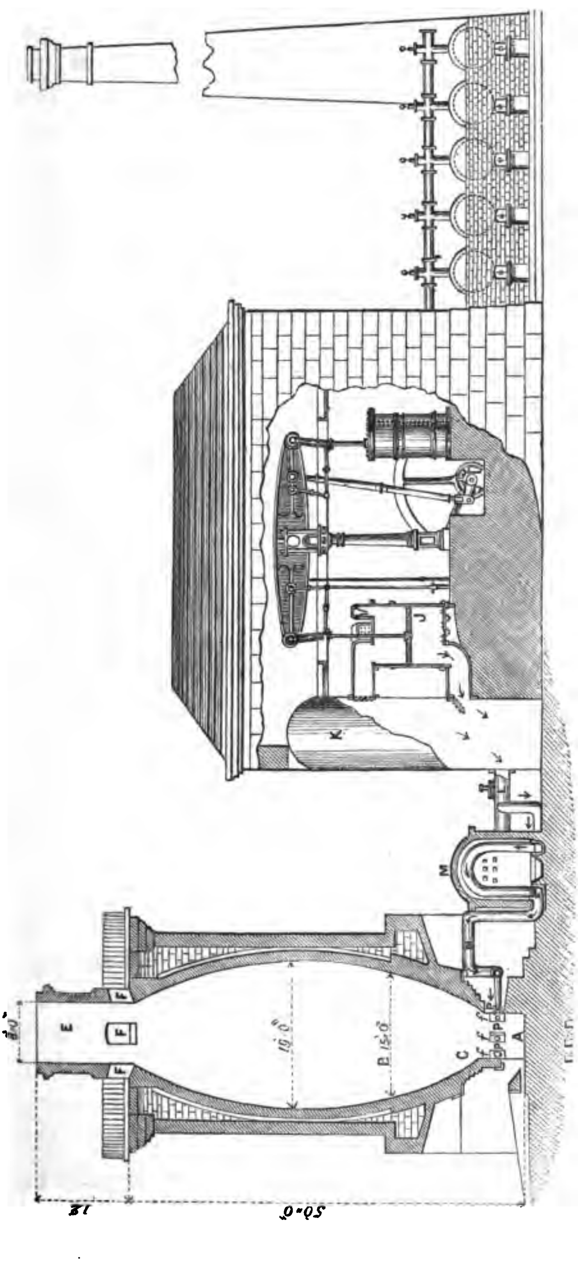

Fig. 18. General Arrangement.

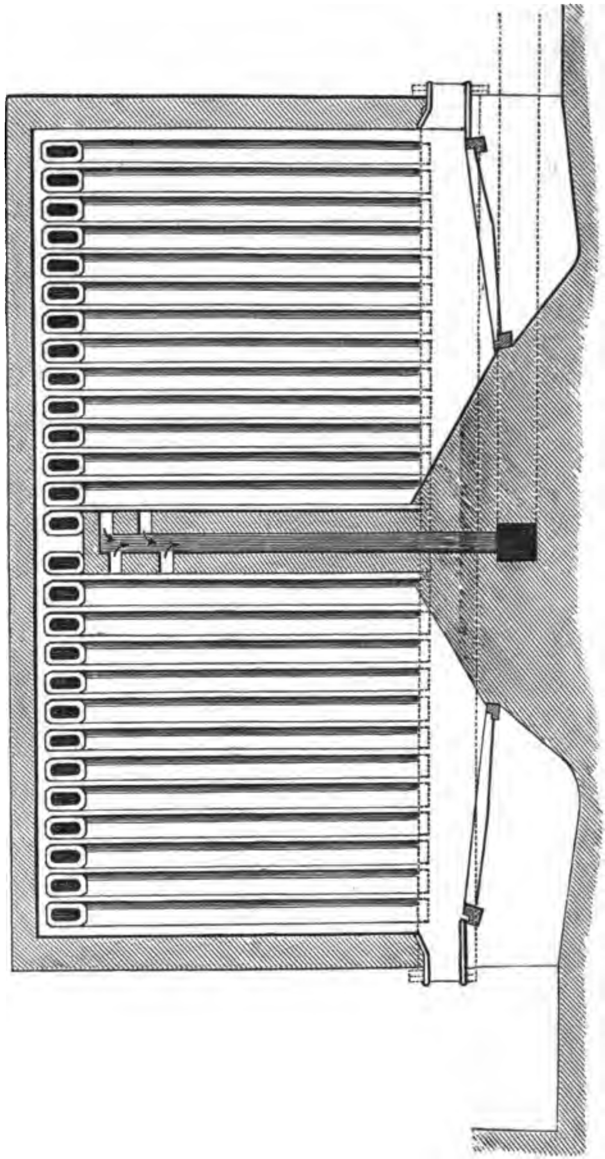

Fig. 19. Hot-blast Stove

creased the production and diminished the consumption of coal three or four fold; and the upholders of the cold-blast maintain that the same effects may be produced, to almost the same extent, by a judicious proportion of the shape and size of the interior of the furnace, a denser blast, and greater attention on the part of the superintendent to the process.

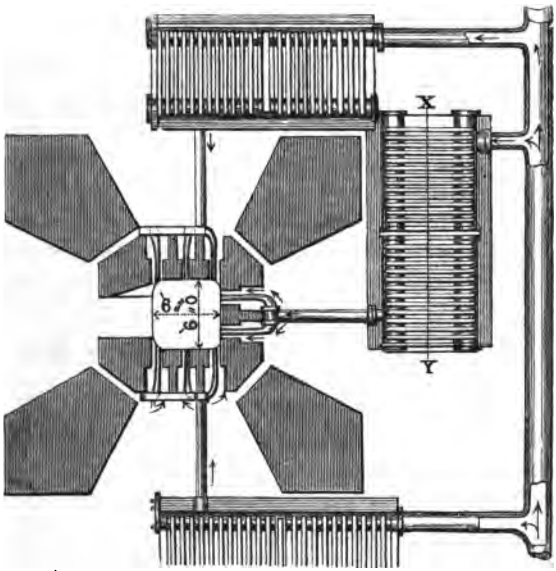

Fig. 20. Plan.

On these points it appears to us, that although the hot-blast has enabled the manufacturer to smelt inferior ores, cinder-heaps, and other improper materials, and to send into the market an inferior description of iron, this is no reason for its rejection, but rather an argument in its favour. It is true that when a strong rigid iron is required for such works as bridges or artillery, the somewhat uncertain character of hot-blast metal renders it objectionable, but this appears to be due rather to carelessness or want of attention in the manufacture than to the use of heated air or defects in the process.

On the other hand, the hot-blast, by maintaining a higher temperature in the furnace, ensures more effectually the combination of the carbon with the iron, and produces a fluid metal of good working qualities, generally superior to cold-blast iron, in cases where great strength is not required; and, moreover, we have yet to learn why even the strongest and most rigid iron cannot be made by this process. The comparative strength of hot and cold blast iron will, however, be given in another part of this treatise; for the present it is sufficient to observe, that the results of the experiments are not unfavourable to the hot-blast iron, either as regards its resistance to a transverse strain, or its power to resist impact.

Dr. Clark, Professor of Chemistry in the University of Aberdeen, investigated the merits of the hot and cold blast process, in regard to the consumption of fuel, as early as 1834-35. He states, that after the hot-blast had been brought fully into operation at the Clyde Ironworks, "during the first six months of the year 1833, one ton of cast-iron was made by means of 2 tons 5¼ cwts. of coal, which had not previously to be converted into coke; adding to this 8 cwts. of coal for heating, we have 2 tons 13¼ cwts. of coal required to make one ton of iron. In 1829, when the cold-blast was in operation, 8 tons 1¼ cwts. of coal had to be used. This being almost exactly three times as much, we have from the change of the cold-blast to the hot, combined with the use of coal instead of coke, three times as much now made from the same quantity of coal." Dr. Clark adds the following statistics of the Clyde Ironworks :—

In 1829, the weekly produce of three furnaces, cold air and coke being used, was 110 tons 14 cwts.; and the average of coal to one ton of iron was 8 tons 1 cwt. 1 qr.

In 1830, the weekly produce of three furnaces, coke and air at 300° Fahr. being used, was 162 tons 2 cwts.; and the average of coal to one ton of iron was reduced to 5 tons 3 cwts. 1 qr.

In 1833, the weekly produce of four furnaces, *raw coal* and air heated to 600° being used, was 245 tons; and the average of coal to one ton of iron was reduced to 2 tons 5 cwts. 1 qr.

"On the whole, then, the application of the hot-blast has caused the same fuel to reduce three times as much iron as before, and the same blast twice as much."

This decrease in the amount of fuel and blast required for the reduction of iron, Dr. Clark accounts for by showing, that in an ordinary furnace, "2 cwts. of air a minute, or 6 tons an hour, are ejected into the furnace." This he considers "a tremendous refrigeratory passing through the hottest part of the furnace," and to a great extent repressing the temperature which is necessary for the complete and rapid reduction of the iron.

Mr. Truran considers that "writers on the hot-blast have greatly exaggerated the effects of this invention on the iron manufacture of this country. If we are to believe the majority of them, the great reductions which have been effected within the last twenty-five years, in the quantities of fuel and flux to smelt a given weight of iron, and the large increase of make from the furnaces, is entirely owing to the use of this invention. That the hot-blast, under certain circumstances, has effected a saving in the consumption of fuel, and also augmented the weekly make, we freely admit. But the saving of fuel and increase of make due to its employment is not generally one-fourth of the quantity which writers have asserted." Here Mr. Truran is at issue with Dr. Clark, and denies the cooling effect of a cold-blast. He attributes the effects of a heated blast, "first, to the caloric thrown into the furnace along with the blast, enabling a corresponding quantity of coal to be withdrawn from the burden of materials, with a proportionate reduction in the volume of blast, the effects of which are seen in an augmentation of the make, but do not result in any saving of fuel; secondly, to the reduced volume of blast and

large proportion of caloric which it carries into the furnace, causing a diminished consumption of fuel in the upper parts of the furnace." Although we do not agree with all Mr. Truran's strictures on the hot-blast, the consumption of fuel in the throat is, nevertheless, a question well worthy of investigation. The combustion is of course largely increased by the narrow form of throat given to furnaces, which greatly increases the effect of the blast there, and accounts for the difficulty of using those kinds of coal, in the raw state, which splinter if rapidly heated. If Mr. Truran's conjectures be correct, and it be found that, by increasing the area of the throat, raw coal and anthracite can be advantageously used with a cold-blast, the superiority of the hot-blast will not be so decidedly marked. This must, however, be determined by practice; as at present certainly it is well known that the anthracite and splint coal can be used most effectively and economically with the hot-blast.

We quote from one more authority on this subject. M. Dufrénoy, in his report to the Director-General of Mines in France, states, that upon heating the air proceeding from the blowing cylinder up to 612° Fahr., a considerable saving in fuel was effected by the use of raw coal instead of coke, and that this caused no derangement of the working of the furnace or deterioration of the iron produced. On the contrary, "the quality of the metal was improved, and a furnace which, when charged with coke, produced only about half No. 1 and half No. 2 pig-iron, gave a much larger proportion of No. 1 after the substitution of raw coal. Besides this, the quantity of limestone was considerably diminished." This last circumstance, according to M. Dufrénoy, is due to the increased temperature of the furnace, which fuses more readily the earthy matter and other impurities in combination with the ores.

To show the saving effected, M. Dufrénoy gives the

quantities used in each of the experiments at the Clyde Iron-works:—

In 1829, the combustion being produced by cold air, the consumption for one ton of iron was—

	Tons.	cwts.	Tons.	cwts.
Coal—for fusion, 3 tons of coke corresponding with . .	6	13		
„ for blowing engine . .	1	0		
Total coal used			7	13
Limestone			0	$10\frac{1}{2}$

In 1831, the furnace being blown with air heated to 450° Fahr.—

	Tons.	cwts.	Tons.	cwts.
Coal—for fusion, 1 ton 18 cwts. coke, corresponding with . .	4	6		
„ for the hot-air apparatus .	0	5		
„ for blowing engine . .	0	7		
Total coal used			4	18
Limestone			0	9

In July 1833, the temperature of the blast being raised to 612° Fahr. and the fusion effected by *raw coal*, the consumption per ton of iron was—

	Tons.	cwts.	Tons.	cwts.
Coal—for fusion . . .	2	0		
„ for the hot-air apparatus .	0	8		
„ for blowing engine . .	0	11		
Total coal used			2	19
Limestone			0	7

Since that time, the employment of a blast heated to 800° or 900° has still further increased the weekly production and saving of fuel.

It has been considered, and no doubt with truth, that the introduction of the hot-blast has led to the reduction of inferior ores, and that the deterioration commonly ascribed to hot-blast iron has arisen from that cause. To some extent this may be the case; but we must look to another cause for many of the anomalous conditions of iron from the same furnaces. If it could be traced to the ores alone, there is at once a solution of the difficulty; but the use of raw coal and uncalcined ore,

with an elevation of temperature arising from the heated blast, and causing the reduction of a larger quantity of impurities, has doubtless something to do with the variable products which proceed from the process. Time, and the purification of the ores and fuel previous to smelting, appear to be essential to the production of good iron; and hence it follows that the high temperature, together with the impurities of the material, is more likely to produce iron of inferior quality than the old process with duly prepared ores and fuel. With this proviso, it does not appear that the hot-blast necessarily deteriorates the iron produced.

The Gases formed in the Blast-Furnace.—The subject of the gaseous products formed in smelting-furnaces at various depths, has been studied with great care by Messrs. Bunsen and Playfair; and the results of their investigations are to be found in a report addressed to the British Association in 1845. The apparatus they employed consisted of a system of malleable iron tubes, connected together to a length of twenty-six feet, and balanced vertically over the smelting-furnace, so as to descend gradually with the charges of iron and fuel. The tube sank three feet per hour at first, and more slowly afterwards. The gases were conveyed by a leaden tube to a convenient position, where samples were sealed in glass tubes for experiment.

The furnace was supplied by a hot-blast, at a temperature of 626° Fahr., at a pressure of 6·75 inches of mercury. The charge consisted of 420 lbs. of calcined ironstone, 390 lbs. of coal, and 170 lbs. of limestone—the product of which is 140 lbs. of pig-iron. The following results were obtained by eudiometric analysis, showing the percentage composition of the gases obtained at depths from the charging platform, varying from 5 to 34 feet:—

TABLE *of Analyses of Gases at Alfreton.*

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
Depth under the top, in feet . . .	5	8	11	14	17	20	23	24	34
Nitrogen . .	55·35	54·77	52·57	50·95	55·49	60·46	58·28	56·75	58·05
Carbonic acid	7·77	9·42	9·41	9·10	12·43	10·83	8·19	10·08	0·00
Carbonic oxide	25·97	20·24	23·16	19·32	18·77	19·43	29·97	25·19	37·43
Light carburetted hydrogen . . .	3·75	8·23	4·57	6·64	4·31	4·40	1·64	2·33	0·00
Hydrogen . .	6·73	6·49	9·33	12·42	7·62	4·83	4·92	5·65	3·18
Olefiant gas .	0·43	0·85	0·95	1·57	1·38	0·00	0·00	0·00	0·00
Cyanogen . .	0·00	0·00	0·00	0·00	0·00	0·00	trace	trace	1·34

The conclusions arrived at by Messrs. Playfair and Bunsen, from a consideration of the above analyses, may be stated as follows :—1*st*, That light carburetted hydrogen being a product of distillation, the coking process extends to a depth of twenty-four feet in the furnace, and the process of distillation of the coal reaches its maximum at a depth of fourteen feet. The vapours of tar are decomposed in the upper part of the furnace. 2*d*, The quantities of carbonic acid and carbonic oxide are *not* mutually dependent. This is due to the subjection of the ore to a simultaneous process of *reduction* by the oxidation of the carbonic oxide, and of *oxidation* by the steam escaping from the coal. The gases could not be collected at a depth lower than the top of the boshes. If the reduction of the ore and evolution of carbonic acid from the limestone had been completely effected above the point of the furnace to which they reached, the gases formed below would have contained their nitrogen and oxygen in the same proportion as in air, or as 79·2 : 20·8. It will be seen that this is not the case from the following table :—

Depth in feet	5	8	11	14	17	20	23	24	34
Nitrogen . .	79·2	79·2	79·2	79·2	79·2	79·2	79·2	79·2	79·2
Oxygen . .	24·9	23·6	24·6	19·5	25·7	23·7	28·2	27·7	27·8

The constant proportion 79·2 to 27 at the 24 and 34 feet proves that in hot-blast furnaces fed with coal the reduction of the iron and the expulsion of the carbonic acid of the limestone takes place in the boshes of the furnace. This depression of the point of reduction so much lower than in the continental charcoal furnace, Messrs. Bunsen and Playfair attribute to the prolongation of the coking process, and the consequent reduction of the temperature in the upper parts of the furnace.

The following results have been obtained by Mr. Ebelman, who has investigated the same subject with care, and do not agree strictly with those obtained by the English chemists. The first results are from a charcoal furnace at Clerval, working with cold-blast under a pressure of 0·44 inches of mercury. The charges consisted of 253 lbs. of charcoal, 397

	I.	II.	III.		IV.	V.	VI.	VII.
Depth from top in feet . .	3¾	3¾	9¾	9¾	19½	19½	27	Tymp.
Carbonic acid	12·01	11·95	4·14	4·23	0·49	0·07	0·00	0·93
Carbonic oxide	24·65	23·85	31·56	31·34	35·05	35·47	37·55	39·86
Hydrogen . .	5·19	4·31	3·04	2·77	1·06	1·09	1·13	0·79
Carburetted hydrogen. .	0·93	1·33	0·34	0·77	0·36	0·31	0·10	0·25
Nitrogen . .	57·22	58·56	60·92	60·89	63·04	63.06	61·22	58·17
Totals . . .	100·00	100·00	100·00	100·00	100.00	100·00	100·00	100·00
Oxygen per 100 nitrogen	42·5	40·8	32·7	32·7	28·5	28·2	30·7	35·8
Carbon vapour per 100 nitrogen . .	32·8	31·7	29·6	29·6	28·5	28·5	30·7	35·9

lbs. of ores, and 254 lbs. of limestone.* I. Gas taken a short time after charging. II. Gas taken a quarter of an hour after charging. III. Gas obtained through a four-inch cast-iron tube. IV. Gas obtained by boring the masonry. V. The same an hour after. VI. Gas obtained by boring the masonry 3½ feet above the tuyeres, and collected through porcelain tubes. VII. Gas obtained through gun-barrels lined with porcelain.

The above results show a progressive diminution of carbonic acid, and a similar increase of carbonic oxide, till at 27 feet from the top the former is entirely absent.

The following results were obtained at the coke furnace at Seraing, the blast being heated to 212°, and the charges consisting of 1434 lbs. of unroasted ores, 1434 lbs. of forge cinders, 948 lbs. of limestone, and 1765 lbs. of coke :—

	I.		II.	III.	IV.		V.	VI.
Depth from top in feet . .	1	1	4	9	10	10	12	45
Carbonic acid	11·39	11·39	9·85	1·54	1·08	1·13	0·10	0·00
Carbonic oxide.	28·61	28·43	28·06	33·88	35·20	35·35	36·30	45·05
Hydrogen . .	2·71	3·04	0·97	0·69	1·72	2·08	2·01	0·25
Carburetted hydrogen .	0·20	...	1·48	1·43	0·33	0·29	0·25	0·07
Nitrogen . .	57·06	56·64	59·64	62·46	61·67	61·15	61·34	54·63
Totals . . .	100·00	100·00	100·00	100.00	100·00	100·00	100·00	100·00
Oxygen per 100 nitrogen	45·0	45·6	40·0	29·6	30·2	30·6	29·9	41·2
Carbon vapour per 100 nitrogen . .	35·2	35·7	33·0	29·4	29·6	30·0	29·9	41·3

I. and II. Gas obtained through iron tube, about 1 inch diameter.

* Annales des Mines, vol. xix. 1851.

VI. Gas obtained by boring through the masonry 2 feet above the tuyeres.

This furnace was 50 feet high. Ebelman draws from his experiments the following general conclusions:—

That the amount of carburetted hydrogen in the furnace gases is too small to affect the chemical reactions in the furnace.

That the air thrown in produces successively carbonic acid and carbonic oxide at a small distance from the tuyere; the former attended by a disengagement of heat; the latter by a re-absorption of the principal part previously disengaged. The limits of the zone of fusion bear relation to this reaction.

The ascending current of carbonic oxide and nitrogen produces these effects: it heats the descending column of minerals; it becomes charged with volatile products disengaged from the fuel, the limestone, etc.; and it reduces the oxide of iron to the metallic state.

The zone in which carbonic oxide exists alone is much more extended in coke than in charcoal furnaces.

The discordance between these results and those obtained by Messrs. Bunsen and Playfair, is attributed by Mr. Ebelman to the employment by the former of long and narrow iron tubes for collecting the gases, which, becoming intensely heated, and charged with dust projected into them by the blast, modified the constitution of the escaping gases.

Utilisation of the Waste Products of the Blast-Furnace.—More than half a century has elapsed since the important practical problem of the utilisation of the waste gases of iron-smelting furnaces was solved in a satisfactory manner in France; and yet it is only twenty-five years ago that it began to attract the serious attention of ironmasters, not only in Great Britain, but on the Continent of Europe.

In June 1814, Berthier published an interesting and important paper on the successful application in France of the

waste gas to various purposes, such as the conversion of iron into steel by cementation, and the burning of lime and bricks. The credit of this application is due to M. Aubertot, who was a proprietor of ironworks in the department of Cher. He obtained a patent for it in France in 1814, and contented himself with only reserving for his own exclusive use that part which was connected with the manufacture of steel by cementation. It is only just to the memory of M. Aubertot to state that he seemed clearly to have foreseen the value of the application in question.

The utilization of the waste heat of blast-furnaces for similar purposes, and on substantially the same principle as Aubertot's method, was patented in England in 1832 by a Mr. Moses Teague.

The foregoing investigations of Messrs. Bunsen and Playfair led them to the conclusion that in the furnaces at Alfreton 81·5 per cent of the fuel is lost in the form of combustible matter still fit for use, or that 11·4 tons of coal are wasted in the twenty-four hours; and that these gases were capable of generating a temperature by their combustion sufficient to melt iron.

In consequence, very many attempts have been made to collect these and apply them to useful purposes in generating steam, or heating the hot-blast oven, and to prevent their useless dissipation in the atmosphere. Proposals of this kind were made as early as the latter part of the eighteenth century, as is shown by the records of the Patent Office. Perhaps the earliest rational plan of this kind was that of Meckenheim in 1842, who proposed to draw off the gases by pipes placed 10 or 15 feet below the tunnel-head, the compression of the blast being sufficient to force them into the pipes. This plan, with various modifications, has since been successfully adopted, the pressure of the gases beneath the surface of the materials having been found by Bunsen and Playfair to be—

Column of Water.		Column of Water.
At 5 feet = 0·12 inch.		At 20 feet = 1·80 inch.
8 „ = 0·40 „		23 „ = 4·70 „
11 „ = 1·10 „		24 „ = 5·10 „
14 „ = 1·60 „		

In 1845 Mr. James Palmer Budd obtained a patent for the application of the "heat, flames, and gases of the blast-furnace" to the heating of hot-blast stoves. This application was carried into practice in the Swansea Valley, at the Ystalyfera furnaces, working with anthracite as the fuel. The hot-blast stove consisted of a chamber containing two horizontal cast-iron mains at the bottom—one for the admission of the cold-blast, and the other for the exit of the hot-blast—the two mains being connected together by cross pipes supporting numerous vertical siphon pipes of cast-iron. The stove was built at the side of the upper part of the furnace, one such stove being thus connected in the brickwork between two adjacent furnaces. Each stove was connected with a stack about 25 feet higher than the mouth of the furnace. The gas was conveyed into the stoves by 3 or 4 horizontal flues, of about 12 inches in diameter, proceeding from opposite sides of each furnace at about 3 feet below the mouth.

To enable the waste gases to be collected and applied to raising steam, heating hot-blast stoves, etc., without detriment to the working of the blast-furnace, it is necessary to withdraw them at an elevation where they have completed their work, yet at such a distance from the mouth of the furnace that they may be extracted in a dry state, and before they come into contact with the atmosphere, so as to cause combustion. This may be effected, either by increasing the height of the blast-furnace, withdrawing a portion of the gases through apertures in the side, or, if the furnace be not too large, by closing the top of the furnace with a movable door. Fig. 21 shows the first plan; AA are the apertures through which the gases escape by the chamber BB into the

pipe C, which conveys them to the place where they are burnt. The requisite pressure for causing the gases to escape at AA

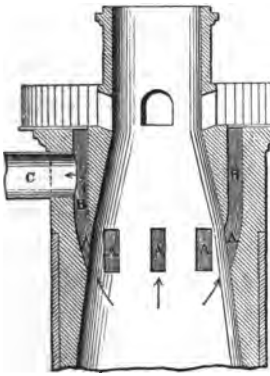

Fig. 21.

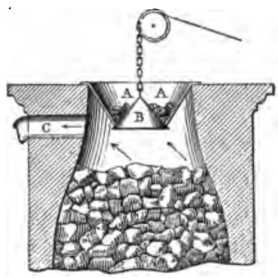

Fig. 22.

is obtained by heaping the charges of fuel and ore to some height above them, and narrowing the upper part of the furnace. To prevent the admixture of atmospheric air, and the consequent ignition of the gases before their arrival at that point where their heat is to be utilised, the openings should be 10 or 15 feet below the surface of the materials. In this way a sufficient pressure is obtained to force the gases into the annular chamber BB, and through the pipe C. Fig. 22 shows another contrivance for the same purpose. A casting AA, in the shape of a truncated cone, is fixed at the top of the furnace, the small diameter downwards; the aperture in the bottom of this is closed by another conical casting B, supported by a chain and counterpoise weight; this evidently shuts the mouth of the furnace, and the gases pass off by the pipe C. When a charge is to be thrown in, it is emptied into the cone hopper AA. When the charge is complete, the movable cone B is lowered so as to enable the charge to pass between it and the edges of the hopper, when it is again raised, and the operations of the furnace proceed as before.

This method of distributing the materials towards the periphery of the furnace is said to be favourable to its working, and the plan of closed tops has been most successful in South Wales. The gases are conveyed away by a three-feet or four-feet pipe, supplied with large valves to prevent danger from explosion, and applied either to heating the boilers of the blowing-engine, or to heating the blast.

In this country sufficient attention has not been paid to this economical practice, as compared with what has been done in other countries where fuel is expensive. It is no excuse that fuel is cheap, as in most cases the gases can be applied with economy, and their combustion tends to abate the serious nuisance of smoke. When first attempted in Staffordshire, the means adopted so altered the working of the furnaces, and caused so much irregularity, that the plan was abandoned. Mr. Blackwell, who has very successfully utilised the gases in some cases, records an instance of the way in which this happened. In 1852 a furnace was placed under his direction, from which the gases were taken off for heating the blast, in which he adopted a plan similar to that shown in Fig. 22. The furnace with this arrangement worked regularly, and carried a good burden; but white iron alone was produced. The burden was lightened, but the iron remained white. A yet further lightening of the burden was made; but, although the cinder was exceedingly grey, still the iron was white. It became evident that a still greater proportion of coke would not produce the desired effect, and was, in fact, useless. The white iron was the effect of the closed top. It was found necessary to sacrifice the gases for the production of grey iron. The white iron had been caused by the pressure produced by the closed top, to which the furnace was most sensitive. But, on the whole, no plan is so effective, or so little interferes with the working of the furnace, as that generally employed in South Wales, and shown in Fig. 22.

As the blast-furnaces of Messrs. Schneider and Hannay of Ulverstone embody some of the latest improvements, a brief description of them may be worthy of notice.

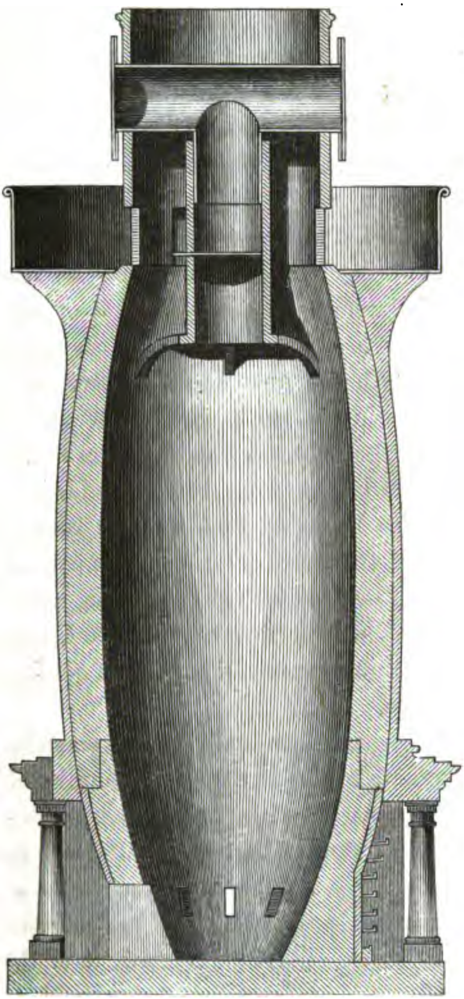

Fig 23.—Schneider's Blast-Furnace.—Sectional Elevation.

The furnaces, Fig. 23, are 42 feet high, 11 feet wide at the mouth, 16 feet 6 inches wide at the boshes, and 7 feet

at the hearth. The tuyeres, of which there are six placed at regular intervals apart, are inserted three feet above the bottom of the hearth. The method of drawing off the waste gases is by a tube descending six feet into the furnace where it is supported by six arms of brick. The diameter of the tube is about one-third that of the mouth of the furnace. It will thus be seen that a portion only of the gases is economized. The object of leading the gases away from the centre by the plan described, is to admit of the charges of ore, fuel, and limestone being distributed equally, so that the working of the furnace may be rendered more regular than is found to be the case by the "cup and cone" plan. Large fans, to assist in drawing off the gases, are placed in connection with the flues which receive the products of their combustion in the stoves and under the boilers. The arrangement of the tubes in the air-stoves is found to work satisfactorily, and leakage is said to be avoided.

It should also be stated, that in those furnaces in which coke is employed the waste gases may in a similar manner be rendered useful, by conducting the coking process in close ovens, and conveying the liberated gases to the steam-boilers, in place of the ordinary wasteful method of coking in the open air in large heaps.

The crude pig-iron produced in the smelting-furnace is assorted, according to the degree and uniformity of its carburisation, and is classed by the ironmaster as No. 1, 2, or 3, according to the amount of carbon it contains. No. 1 is most highly carburised, No. 2 less so, and so on to a No. 4 iron, which is sometimes produced. The carbon combined with the iron gives it fusibility, but deprives it of ductility. To render it malleable and capable of being welded, it must be deprived, as far as possible, of all extraneous substances which have been mixed with it in the blast-furnace, more especially of carbon.

The carbon exists in the cast-iron in two forms; it is either combined with the iron chemically, or it is mechanically mixed with it in graphitic scales, which can be perceived with a microscope. The amount of carbon in cast-iron varies from 2 to 4 per cent; of this the greater part is graphitic in grey iron; in mottled iron it is partly combined, partly graphitic; and in white iron it is wholly combined. Usually white iron contains less carbon than grey; but this is not a constant characteristic.

Manganese is present in cast-iron, being reduced in the smelting process to the extent of from 0·7 to 4 per cent, and on the average 2 per cent. A part of the silica of the ores is also reduced, and appears to form an alloy with the iron. The amount of silicium varies between the limits of 0·3 and 3 per cent, and appears to be greater in hot than cold blast iron.

The sulphuret of iron in the ores and fuel is partly decomposed and carried off by smelting as sulphuret of calcium, and partly remains in the iron, rendering it red-short and injuring its tenacity. Mr. Calvert of Manchester has proposed to eliminate this injurious constituent by the use of chlorides (by preference common salt) in the coking and calcining or smelting processes. Chloride of sodium has been used for a similar purpose in the puddling process in Belgium. The amount of sulphur varies up to 0·1 per cent; and in some cases to 1 per cent.

Phosphorus in the ores or fuel passes mostly into the cast-iron, and has a most pernicious effect. It is believed to render the iron cold-short. Its amount varies up to 1·5 per cent.

On this subject the following extracts from Dr. Price and Mr. E. C. Nicholson may be interesting:—

" The employment of the hot-blast in the smelting of iron is supposed to occasion the production of pig-iron of inferior

quality, that is to say, contaminated with larger amounts of foreign elements than that smelted with cold-blast.

"In the present communication it is not our intention to enter upon the discussion of this subject generally, as we intend reserving this for a future communication, but to limit our remarks to the consideration of the supposed influence of hot-blast in augmenting the quantity of phosphorus, an element of almost constant occurrence in pig-iron, and to the presence of which in bar-iron the peculiar property of the metal known as *cold shortness* is attributed.

"In a paper published in the Quarterly Journal of the Chemical Society, and also in one read before the British Association in 1849, by Mr. Wrightson, several analyses of cast-iron, the produce of Staffordshire furnaces worked by hot, warm, and cold blast, are given to prove that a larger amount of phosphoric acid is reduced when hot-blast is employed.

"The increase in the percentage of phosphorus in the iron smelted with hot over that with cold blast is exhibited in the following series of Mr. Wrightson's results:—

	1	2	3	4	5	6	7	8
Hot-blast . . .	0·51	0·55	0·50	0·71	0·54	...	0·07	0·40
Cold-blast . . .	0·47	0·41	0·31	0·20	0·21	0·36	0·03	0·36
Increase of P. in hot-blast . .	0·04	0·14	0·19	0·51	0·33	...	0·04	0·04

"The ores from which the iron was smelted were also analysed, and found to contain the following percentages of phosphoric acid:—

Binds.	Blue flats.	Penny earth.	Gubbin.	White ironstone.	White free.	Black free.
traces.	traces.	1·00	0·32	0·95	0·90	trace.

"The increase in the amount of phosphorus indicated in the above table as occurring in hot-blast iron, does not, in the absence of a knowledge of the relative quantities of the re-

spective ores employed, which vary as much as 1 per cent in the quantity of phosphoric acid which they contain, and also of an examination of the blast-furnace slag produced, appear to afford sufficient proof in support of this opinion.

"Karsten,* in speaking of bog-iron ore, says, that, when smelted, the whole of the phosphate of iron is reduced to the state of phosphide and absorbed by the iron. Berthier,† from experiments conducted on a small scale, does not coincide with this view, and considers that the difficulty of detecting small quantities of phosphoric acid must account for its not appearing amongst the constituents in the various analyses of blast-furnace slags which he has described in his work.

"From experiments made by assaying pure hæmatite with variable percentages of phosphate of lime‡ and suitable proportions of flux and charcoal, we have by analysing the buttons of metal and slags obtained, taking care to select those only in which the operation was perfect—that is to say, in which a colourless slag and graphitous button were produced—also corroborated Berthier's results, as will be apparent from the following table:—

Pure peroxide of iron.	Phosphate of lime.	Flux.	Coke.	Percentage of phosphorus in button.	
				Calculated.	Found.
1. 10·0 grms.	0·25 grms.	10·0 grms.	2·25 grms.	0·60	0·56
2. 10·0 "	0.75 "	10·0 "	2·25 "	1·83	1·60
3. 10·0 "	2·50 "	10·0 "	2·50 "	6·20	2·60
4. 10·0 "	5·00 "	10·0 "	2·50 "	12·60	6.00

"In the assay of ores, and also of scoriæ from forge and mill furnaces, which contain a large amount of phosphoric acid, results widely different to the foregoing were arrived at.

* Handbuch der Eisenhüttenkunde, vol. ii. § 368. Berlin, 1841.

† Traité des Essais par la Voie sêche, vol. ii. p. 262.

‡ The amount of phosphoric acid in the phosphate of lime was previously determined.

The following, selected from a great number of experiments, are marked illustrations of this :—

		Lime.	Coke.	Flux.	Percentage of phosphorus in button.	
					Calculated.	Found.
	grms.	grms.	grms.	grms.		
5. Welsh black-band ordinary quality—calcined	10·0	3·5	1·75	...	0·82	0·81
6. Argillaceous iron ore—calcined, very rich in phosphoric acid . . .	10·0	1·5	1·20	...	6·60	6·41
7. Brown hæmatite, also rich in phosphoric acid	10·0	...	...	10·0	6·90	6·70
8. Scoria from puddling-furnace	10·0	...	2·0	10·0	13·6	12·5
9. Scoria from balling-furnace	10·0	...	2·0	10·0	2·27	2·25

"The time occupied in performing the assays, and the furnace conditions under which they were conducted, were about the same in all cases. Where flux was employed, it consisted of two parts of clay-shale and one part of lime.

"It is necessary to state, that the phosphoric acid in the ores above cited was in combination with lime. In the cinders it existed as phosphate of iron.

"In experiments Nos. 1 and 2, it will be seen that the quantity of phosphorus found agrees pretty well with the theoretical amount, whilst in 3 and 4 it falls considerably short. That this is owing to the length of time during which the reduction process is carried on we have no doubt, as we have frequently repeated the assays with the same proportions, and have found the amount of phosphorus in the button to vary considerably, never having succeeded in obtaining more than four-fifths of the total quantity. If, however, the cementation were prolonged for a sufficient length of time, it is very probable that the whole of the phosphoric acid would be reduced.

"We have undertaken many experiments upon the large scale with the view of deciding this point. For this purpose we have determined the amount of phosphorus in iron that had been smelted from argillaceous ores by cold-blast, and by a blast heated to 600° Fahr.

"The following are the results :—

	I.	II.	III.	IV.
Hot-blast . . .	0·74	0·68	0·71	0·58
	V.	VI.	VII.	VIII.*
Cold-blast . . .	0·81	0·62	0·68	0·63

"The iron in both cases was what is known as good No. 2 foundry pig.

"In two instances it will be seen that the percentage of phosphorus is higher in the cold-blast iron than in the hot; but the difference in these and in the other two is so slight, that it may fairly be attributed to the variations in the composition of the ore.

"The slags produced simultaneously with four of the above irons were examined for phosphoric acid by the usual methods, as well as by molybdate of ammonia; and it was only by the latter re-agent that we were able to find minute traces. We append the analyses of the slags :—

	I.	II.	V.	VI.
Silicic acid . . .	39·95	40·20	41·64	42·94
Alumina	17·41	16·45	13·20	16·29
Lime	29·64	30·00	35·91	31·10
Magnesia	6·47	7·29	4·21	4·16
Protoxide of iron .	0·24	0·57	0·11	0·34
Protoxide of manganese	0·91	0·84	0·74	0·51
Sulphide of calcium .	3·60	2·71	2·19	2·16
Alkalies	1·46	1·30	1·70	1·87
Phosphoric acid . .	trace	trace	trace	trace
Loss	0·32	0·64	0·30	0·63
	100·00	100·00	100·00	100·00

* These correspond with the percentage amounts of phosphorus, calculated from the analyses of the ores, that the pig-iron should contain if all the phosphoric acid were reduced.

"As far as our experience enables us to judge, we incline to the opinion that when the process of reduction is complete, or nearly so—that is to say, when no oxide of iron, or small quantities only, pass off with the slag—that then the whole of the phosphoric acid is reduced, and the phosphorus absorbed by the iron independently of the temperature of the blast. The analyses above given prove such to be the case with the iron smelted from the ores ordinarily employed in this country, in which the amount of phosphoric acid seldom exceeds 1 per cent.

"With ores and scoriæ containing large amounts of phosphoric acid, we have also had opportunities of proving that, when smelted with hot-blast, all the phosphoric acid is reduced, and the phosphorus absorbed by the iron; this we have found to be the case with ores containing from 2 to 3 per cent of phosphoric acid, and with scoriæ with as much as from 8 to 10 per cent; but we have not had an opportunity of examining a product smelted with cold-blast from similar materials.

"The following exhibits the percentage of phosphorus (IX.) in grey pig-iron smelted with hot-blast from pisolitic iron ore; (X.) of grey pig-iron smelted with hot-blast from puddling-furnace scoriæ and clay-shale:—

IX.	X.
2·56	6·94

"The slags respectively made with these products had the following composition:—

	IX.	X.
Silicic acid	45·64	41·11
Alumina	10·84	9·46
Lime	35·01	37·90
Magnesia	3·16	2·11
Protoxide of iron	0·71	0·39
Protoxide of manganese	trace	1·61
Sulphide of calcium	3·30	6·41
Alkalies	0·82	0·71
Phosphoric acid	trace	trace
Loss	0·52	0·30
	100·00	100·00

"Phosphoric acid is present in blast-furnace slags when white iron is being smelted; that is, when the slag contains appreciable quantities of protoxide of iron, as will be seen by the following analyses :—

	XI.	XII.
Silicic acid	41·11	37·84
Alumina	13·45	13·20
Lime	29·82	20·68
Magnesia	4·75	2·93
Protoxide of iron . .	6·44	20·83
Protoxide of manganese .	0·66	0·80
Alkalies	1·84	1·08
Sulphide of calcium . .	1·34	0·87
Phosphoric acid . . .	0·15	1·77
Loss	0·44	0·05
	100·00	100·00

"No. XI. is that of a slag resembling black bottle-glass in appearance, and from its liquidity when melted is termed by the workmen a *scouring slag.* It was from argillaceous ore.

"No. XII. from pisolitic ore when the working of the furnace was much deranged. This slag was exceedingly heavy, of a pitch-black colour, with the surface of the blocks in the *tap-wagons* of the dull, dark red, bronze-like aspect characteristic of very bad furnace slags.

"From these results we must regard the ore as being melted up (not smelted) and flowing away with the slags, although in very different degrees in the two examples given.

"The analyses of crystalline slags by Percy and D. Forbes,* in all of which phosphoric acid was sought, lead to the same inference, phosphoric acid having been discovered and estimated in only one instance, and that in a slag similar to XI. It contained FeO 4·94, and PO^5 0·19.

"In conclusion we will briefly recapitulate the results of our experiments.

* British Association Report, 1846; and Chem. Gaz., vol. v. p. 29.

"*1st,* That in assaying ores, all the phosphorus of the phosphates will be found in the button.

"*2d,* That when the ordinary iron ores—such as the argillaceous ores, blackbands, hæmatites, etc.—are smelted, the iron produced, if it be grey, will contain all the phosphorus of the ore, whether the furnace be driven with hot or cold blast.

"*Lastly,* That the slag may contain phosphoric acid in determinable quantity when white iron is being smelted."

Arsenic, aluminium, calcium, magnesium, sodium, potassium, and a few other metals, are occasionally found in cast-iron; but their influence on its strength and other properties is very little understood.

To prevent the contamination of the crude metal by the impurities of the fuel employed, Dr. Gurlt of Prussia has proposed a system of smelting similar in principle to that of the Silesian puddling-furnaces, which will be described in the next chapter. He proposes to convey the roasted ore, after crushing, into a cupola, the lower portion of which communicates with two close ovens or gas-generators, in which any kind of fuel is submitted to a slow process of distillation and imperfect combustion, so as to produce carburetted hydrogen, carbonic oxide, etc. These gases, on passing into the cupola, are ignited by contact with a stream of air supplied by a blast, and the heat is raised to a temperature calculated to effect the reduction of the ores. In this way the iron is smelted without ever coming in contact with the impurities of the fuel. The subject is an important one, as there are abundance of spathic, hæmatite, and specular ores to supply a very fine quality of iron, if they could be reduced without being contaminated by the unavoidable impurities of coal, coke, or limestone. A great deal has yet to be accomplished in this way, and the subject is well entitled to the close attention of our best analytical chemists.

CHAPTER V.

THE CONVERSION OF CRUDE INTO MALLEABLE IRON.

THE conversion of the carburised crude iron, obtained from the blast-furnace, into malleable or wrought iron, is effected by several operations of an oxidising character, in which it is sought to separate, in the gaseous state, the carbon contained in the iron, by combining it with oxygen, whilst the other metals alloyed with the iron, and the phosphorus, pass into the slag.*

Methods of Conversion with Charcoal and Coke Iron.—In reference to subsequent operations, the iron produced in the smelting-furnace may be divided into two kinds—that reduced by charcoal, and that reduced by coke or raw coal. When charcoal iron has to be converted by charcoal, as in Sweden, it is decarburised in the charcoal refinery, with or without an intervening process. Where coal can be obtained, however, it is now usually converted by the process of puddling. Pig-iron produced by coke or coal is converted into malleable iron either by decarburisation in the refinery or oxidising hearth, and subsequent puddling; or it is converted at once in the puddling-furnace by the process of boiling, which is equally effective, and is now more generally practised.

This last process, as the one most generally adopted in this country, deserves a special notice, and we are fortunate in having before us the particulars of the manner in which it is

* See Mr. Blackwell's paper, On the Iron Industry of Great Britain, read before the Society of Arts.

conducted by Messrs. Rushton and Eckersley of Bolton, kindly furnished by Mr. Rushton, the senior partner of the firm. This establishment is probably one of the most modern and complete of the kind in the kingdom; it is one that has spared no expense in the application of useful inventions, and has kept pace with every improvement that has taken place in the manufacture of bar and plate iron for the last fifteen years.

The machinery and appliances at these works consist of—

6 Steam-engines, of 180 total nominal HP.
2 Five-ton and 2 fifty-cwt. steam-hammers.
3 Helve-hammers.
1 Set of puddled iron rolls.
1 Set of boiler-plate rolls.
1 Merchant train and balling mill.
16 Puddling-furnaces.
14 Balling and scrap furnaces.
And other machinery, such as plate and bar shears, lathes, etc.

Since in all processes of converting, the carbon of the crude metal has to be oxidised and got rid of, *primâ facie*, it would appear that whilst the highly carburised pig-iron is the most suitable for casting, that containing least carbon is best adapted for conversion into malleable iron; hence, in the trade, the crude iron is divided into foundry and forge pigs.

The pigs, however, in which carbon most predominates, and which, as a rule, have been least contaminated with *other* impurities during the process of smelting, are in many respects preferable for the manufacture of wrought-iron. Up to this time, however, great practical difficulties have attended the decarburisation of iron containing so much carbon, and the white or forge iron is almost always preferred, measures having been taken for depriving it of the metals and earthy impurities not separated in the blast-furnace.

The Refining Process.—With regard to the process of refining, we may observe, that the crude iron is melted in a hollow fire, and partially decarburised by the action of a blast

of air forced over its surface by a fan or blowing engine. The carbon, having a greater affinity for the oxygen than for the iron, combines with it, and passes off as gaseous carbonic oxide or carbonic acid. During this process, a portion of the silicum, etc., is fused out, and separated from the iron. It is obvious from the above, that the iron to be refined, being placed in contact with fuel at a high temperature, is liable to be deteriorated by the admixture of sulphur and other impurities of the fuel; and as the iron is only partially exposed to the action of the blast, the operation is necessarily, under these circumstances, imperfect. From the refinery the metal is run out into large moulds, and is then broken up into what is technically distinguished as "*plate metal.*"

Mr. Clay has tried with some success a process of refining, in which the molten crude iron is allowed to fall in minutely divided streams from the top of a tower constructed on the principle of those in which lead is granulated for shot. The carbon is effectually burned off during its fall, owing to the minutely divided condition of the metal, and it is further purified from sulphur and phosphorus by being received in a vessel of water.

The Puddling Process.—The process of puddling succeeds that of refining; and in this operation the reverberatory furnace is employed, with the fire separated by a partition or bridge from the hearth, on which is placed the metal to be puddled. By this arrangement the flame is conducted over the surface of the metal, creating an intense heat, though the deleterious portions of the fuel cannot mix with the iron. Fig. 24 shows the form of the reverberatory furnace in section. It consists externally of an oblong casing of iron plates firmly bound together by iron tie-bars, and lined with fire-brick. A is the fire-grate, separated from the body of the furnace E by a bridge over which the heated products of combustion, with a surplus of oxygen, play upon the surface of the molten

metal, and effect its conversion, and thence pass to a lofty chimney K, over the top of which is suspended a metal plate,

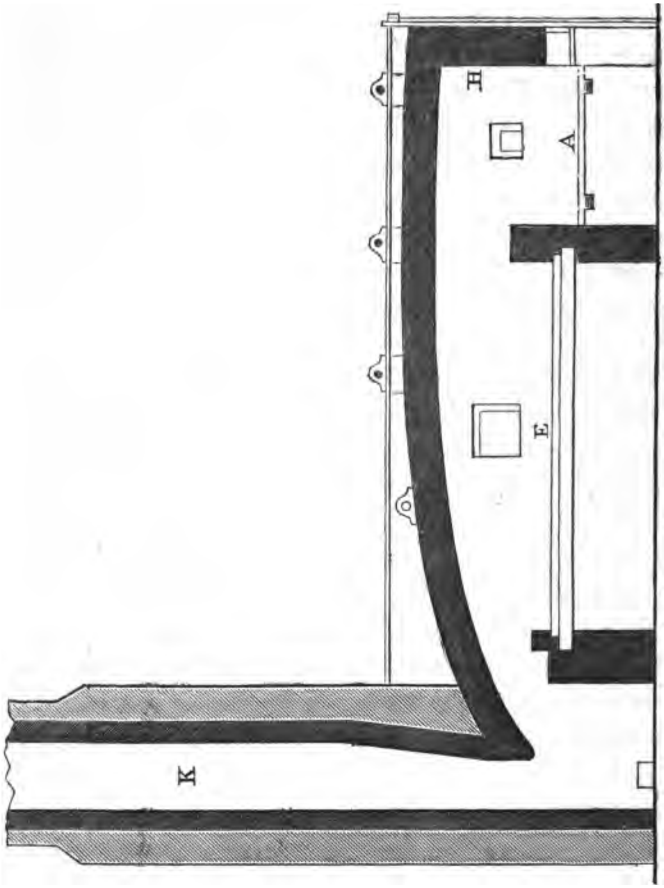

Fig. 24.

by which the draught can be regulated to a nicety. The body of the furnace E is dish-shaped, and constructed of cast-iron plates, the sides being in some cases hollow blocks, through which a stream of water or air is made to circulate to retard their deterioration by the heat. The free access of air to the under side of the plate forming the bottom, in a similar man-

ner conserves that part. The puddler effects his operations through a door balanced by a lever and weight, so as to open or close with ease. In some furnaces the charge of iron, weighing about 4 cwts. before its introduction into the puddling furnace, is raised to a red heat in a chamber provided for that purpose between the body of the furnace and the chimney, and in this way both time and fuel are economised. In the furnace the iron is kept in a state of fusion, whilst the workman, called the "puddler," by means of a rake or *rabble*, agitates the metal so as to expose, as far as he is able, the whole of the charge to the action of the oxygen passing over it from the fire. By this means the carbon is oxidised, and the metal is gradually reduced to a tough, pasty condition, and subsequently to a granular form, somewhat resembling heaps of boiled rice with the grains greatly enlarged. In this condition of the furnace, the cinder or earthy impurities yield to the intense heat, and flow off from the mass over the bottom in a highly fluid state.

At intervals in the process, portions of oxides of iron, hammer scales, scoriæ, and in some cases limestone and common salt, are thrown upon the molten iron, and form a fluid slag, which assists in oxidising the carbon, and removing as silicates, etc., the magnesia, sulphur, and other impurities of the iron.

The iron at this stage is comparatively pure, and quickly becomes capable of agglutination; the puddler then collects the metallic granules or particles with his *rabble*, and rolls them together, backwards and forwards, over the hearth, into balls of convenient dimensions (about the size of thirteen-inch shells), when he removes them from the furnace to be subjected to the action of the hammer or mechanical pressure necessary to give to the iron homogeneity and fibre. This double process of refining and puddling has universally been employed till recently; but improvements have rendered it simpler, and the refining process is now very generally abolished.

The Boiling Process.—Shortly after the employment of the puddling process, it was found advantageous to mix a portion of crude iron with the refined plate metal, the expense of the process of refining being saved upon the iron used in the crude state; and trusting to the decarburising effects of the puddling furnace, it was found that the refining process may be altogether dispensed with, if crude iron containing a proportion of oxygen and very little carbon was employed. In this single process it is to be observed, that as all the carbon has to be got rid of in the puddling-furnace, the evolution of gas is much more violent, the fluid iron boiling and bubbling energetically during the period of its disengagement; and hence the operation has acquired the popular name of the "boiling" process.

In this operation the pig-iron when melted is more fluid, on account of containing a greater proportion of carbon than the metal from the refinery, and requires more labour in stirring it about and submitting it to the action of the current of air; the process moreover is attended with a greater waste of iron than puddling either plate or crude iron and plate mixed, but not so great a loss as in the two operations of refining and puddling. It must, however, be admitted that the superior fluidity of the iron in the boiling process has a more injurious action on the furnace. Notwithstanding these objections, the system of boiling without the intermediate process of refining has been gaining ground for the last ten years, and in many places has entirely superseded the use of the refinery: recent events have therefore led to the conclusion, that in a short time the refining process will have become a thing of the past.

About the time or shortly after this article was written, Mr. Hall, of the firm of Messrs. Barrows and Hall of the Bloomfield Ironworks, Tipton, addressed a letter to the editor of the Birmingham Journal, entitled, Iron Scrap, or the issue of an

old shoe-heel, in which is given an account of a long-continued series of experiments in remelting and extracting from the scrap and slag of puddling-furnaces a quantity of ductile iron. These experiments (according to Mr. Hall) led to the introduction of pig-iron and the boiling system into the puddling-furnace, and as this must have taken place more than thirty years ago, Mr. Hall may safely be considered as the first who introduced the system of boiling which ultimately dispensed with the refinery and established the more expeditious process of puddling direct from the pig.

At Messrs. Rushton and Eckersley's works, a small proportion of Cumberland hæmatite ore, or peroxide of iron, is mixed with the pig-iron to be converted, as it is found to assist in the process of boiling by supplying oxygen in the molten mass, and in other respects facilitating the process, increasing the yield and improving the quality of the metal.

Numerous attempts have been made to secure a more scientific and perfect decarburisation of the crude iron, but without success. One improvement, however, patented in 1854 by Mr. James Nasmyth, gives promise of making the boiling process as nearly perfect as we may hope to see it. It has been in use for some years at the Bolton Ironworks, and from its constant employment in the puddling-furnaces of that establishment, it has given direct proof of its utility, and is gradually extending itself among the large manufacturers as its advantages become known.

The invention consists of the introduction of a small quantity of steam, at about 5 lbs. pressure per square inch, into the molten metal as soon as it is fused. As the oxygen of the steam has at that high temperature a greater affinity for carbon than for the hydrogen with which it is combined, or for the iron, the carbon is rapidly oxidised off. The liberated hydrogen has no affinity for the iron, but unites with sulphur, phosphorus, arsenic, etc.—substances very injurious

to the quality of the iron, if present even in minute quantities, and yet frequently found in the ores and fuel.

The steam has also a mechanical as well as a chemical action on the iron. Being introduced at the bottom of the furnace, and thence diffused upwards, it violently agitates the iron, and causes the exposure of fresh surfaces to the oxygen passing through the furnace.

The mode of operating is as follows :—The steam is conveyed from the boiler to a vertical pipe fixed near the furnace door, having at its lower end a small tap or syphon, to let off the condensed steam, and prevent its being blown into the furnace. A cock with several jointed pieces of pipe are fastened to the flange of the vertical pipe, so as to form, as it were, jointed bracket-pipes, somewhat similar to those of gas-pipes, which allow free motion in every direction, as in the annexed sketch, in which A, Fig. 25, is the reverberatory furnace, *a* the vertical steam-pipe communicating with the

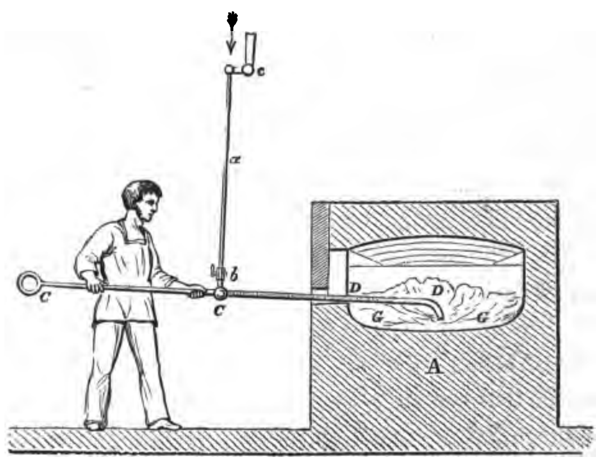

Fig. 25.

boiler, *b* the tap or steam-cock, *cc* the elbow-jointed tubes, CC the handle, and DD the steam-tube or rabble, bent at the end, so as to inject the steam on the liquid metal GG. This

apparatus is introduced into the furnace immediately the iron is melted, the puddler moving it slowly about in the molten iron, while the steam pours upon it through the bent end of the tube. In the course of from five to eight minutes the mass begins to thicken, the steam-pipe is withdrawn, and the operation finished in the ordinary way with the common iron *rabble*. The time saved by this process in every operation, or *heat*, as it is technically called, averages from ten to fifteen minutes, and that during the hottest and most laborious part of the operation.

By means of this apparatus, the highly carburised pig-iron, which is the most free from impurities, is rendered malleable in one furnace operation, without the deteriorating adjuncts of the refining and puddling process as ordinarily practised; in this operation no deleterious substance can combine with the iron, whilst in the refinery process the mixture of the fuel and metal is liable to deteriorate the latter with sulphur, silicum, etc. This new process, it is affirmed, has a beneficial effect in purifying the iron with greater economy and rapidity than any other process with which we are acquainted.

Silesian Gas Puddling-Furnaces.—Irrespective of the improvements just described, there is another which is extensively used on the Continent, denominated the Silesian gas-furnace. For a drawing and explanation of this furnace we are indebted to Mr. Anderson, inspector of machinery at the arsenal, Woolwich. The following drawing, Fig. 26, will explain the new Silesian furnaces which are used in the manufacture of iron in that country, in place of our reverberatory air-furnaces, and are said, on good authority, to be a very great improvement, not only in regard to the entire prevention of smoke and the economy of fuel, but also in simplifying the wrought-iron manufacture, and enabling a less skilled class of workmen to manage the furnaces.

Their general character is that of a reverberatory furnace,

the fireplace of which is replaced by an oblong chamber, 4 feet by 6 feet, and denominated the Gas-generator, which may be described as a close brick chamber with an opening at the bottom for the admission of air from a fan, by means of which the gases are driven out of the chamber into the furnace amongst the iron to be heated. At the point where the gases enter the furnace, a series of tuyeres are provided for the admission of air from the same fan. The pipes that convey the air and the gas from the retort to the tuyeres are both provided with valves, in order that the attendant may modify the quantity from either source, so as to obtain any intensity of flame the work may require, and also to produce perfect combustion, thus placing the entire action of the furnace under complete control. It is about twenty-four years since these furnaces were first introduced; and notwithstanding the prejudices that were naturally raised against them, they are said to be now extensively adopted in the Silesian district, and in great favour with both the master and the workmen.

In this description of furnace there appear to be four great advantages over the air-furnace—

1*st*, The entire absence of smoke, in consequence of complete combustion.

2*d*, The saving of upwards of 33 per cent in fuel, from the whole of the gaseous products being made available, and there being no necessity for the flame to pass up the chimney to produce draught, as in the case of the reverberatory furnace, which requires an inordinate supply of fuel as compared with what is wanted to work the fan.

3*d*, The absolute control the attendant has over the furnace, as regards the temperature, and the simplicity with which it can be worked. Its operations in this respect are, according to those who have seen it at work, so perfect as to be as precise in its action as a machine.

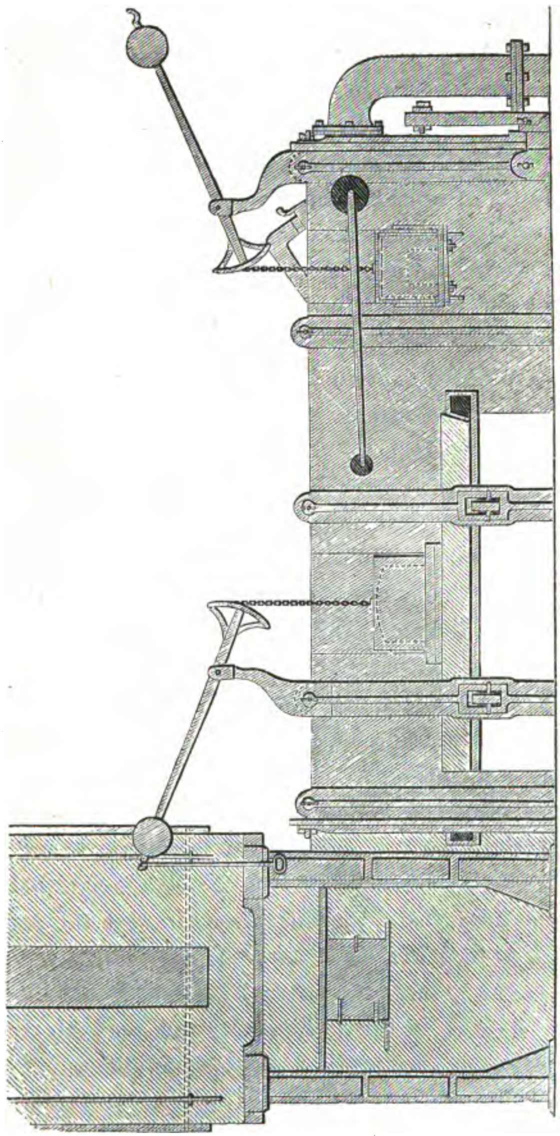

Fig. 26.—Silesian Gas Furnace

4th, The iron is preserved from contact with the ash and impurities of the fuel.

Mr. F. A. Abel, who saw these furnaces at work at the Government Ironworks in Upper Silesia, describes the process of refining in the following way:—When the charge of iron on the hearth is ascertained to be thoroughly fused, a small quantity of crushed limestone is thrown over its surface, and two tuyeres are then introduced into the furnace at an angle of 25° through an opening on each side of the hearth, not far from the bridge. The width of the nozzle employed depends on the power of the blast used; the air rushing from these tuyeres impinges with violence on the iron, and, the two currents meeting, an eddying motion is imparted to the fused metal. In a short time the motion produced in the mass is considerable; the supernatant slag is blown aside by the blast, and the surface of iron thus exposed undergoes refinement, while it changes continually, the temperature of the whole mass being raised to a full white heat by the action of the air. The iron is also stirred occasionally, in order to insure a proper change in the metal exposed to the action of the blast. A shovelful of limestone is occasionally thrown in, the total quantity used being about 1 per cent of the iron employed. The duration of the treatment in this furnace after the fusion of the metal, with a charge of 40 cwts., varies from two and a half to five hours, according to the produce to be obtained. When the charge is to be withdrawn from the furnace, the side tuyere nearest the tap-hole is removed, so that the blast from the opposite tuyere may force the metal towards the hole. The fluid iron, as it flows from the tap-hole, is fully white hot, and perfectly limpid. It chills, however, very rapidly, and soon solidifies.

From this description it would appear that the ironmasters of this country have not made themselves acquainted

with these improvements; but having some knowledge of the efficiency and existence of this process, we would earnestly recommend it to their attention, as an invention, in more respects than one, entitled to consideration.

CHAPTER VI.

THE MECHANICAL OPERATIONS OF THE WROUGHT-IRON MANUFACTURE.

THE mechanical operations connected with the manufacture of wrought-iron consist of shingling, hammering, rolling, etc., to which we may add the forging of "*uses*," that is, the forging of those peculiar forms so extensively in demand for steam-engines, steam-boats, railway carriages, and other works, which has lately become a large and important branch of trade.

In tracing the whole of the processes in the manufacture of wrought-iron bars and plates, it will not be necessary to enlarge on those practices which have been superseded by more modern and improved machinery. Suffice it then to observe, that the puddled balls have to be *shingled* or fashioned into oblong slabs or *blooms* by the blows of a heavy forge-hammer. During this operation, the scoriæ and impurities which adhere to the balls are separated from the blooms by the force of impact, and then by a series of blows the iron is rendered malleable, dense, and compact. The blooms are then passed through a series of grooved iron rollers, which reduce them to the form of long slender iron bars, called puddle-bars. These are cut up and piled regularly together or *fagotted*, and brought to a welding heat in the heating or *balling* furnace, when they are again passed several times through grooved rollers, and by this latter process are made into bars or plates ready for the shears.

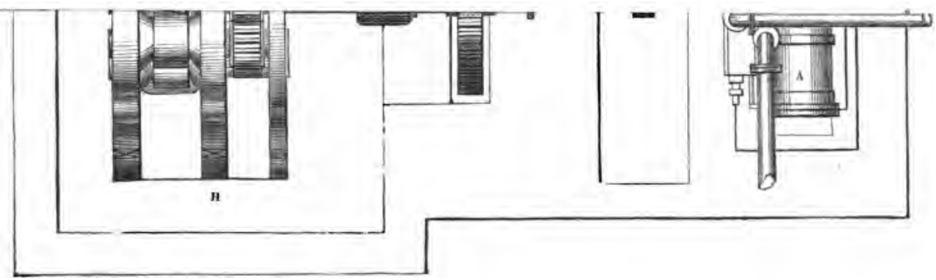

Fig. 27 (p. 117).

In order to arrive at a clear conception of the mechanical operations employed in the manufacture of iron, it will be necessary to describe more at length the processes as at present practised, with the improved and powerful machinery now employed; and as much depends upon the application of the motive power, the steam-engine claims the first notice. Until of late years, the vertical steam-engine was invariably used for giving motion to the forge-hammer and rolling-mill, which were placed on one side of the fly-wheel and the crank on the other; but the high-pressure non-condensing engine is found to be decidedly preferable, as the waste heat passing off with the products of combustion from the puddling and heating furnaces is quite sufficient to raise the steam for working the rolls and one of Brown's bloom-squeezers, as shown in the following drawing.

In this arrangement the cylinder A (Figs 27 and 28) is placed horizontally, and is supplied with steam from boilers near the puddling-furnaces. The piston-rod and slides B, and connecting-rod C, give motion to the crank-shaft D, on which is fixed a heavy fly-wheel E. The puddling rolls F F are driven direct from the end of the fly-wheel shaft, being attached to it by a disengaging coupling C′; the bloom-squeezers H are driven by a train of spur wheels G G. Under the lower rolls of the squeezers a Jacob's ladder or elevator I is fixed, for raising the block which has been deprived of its impurities, and reduced to an oblong shape by passing between the rollers of the squeezer. The block, on leaving the rollers, is carried in front of one of the projecting divisions of the ladder I, and thrown on to the platform in front of the rolls F F; the workman then seizes it with a pair of tongs, and forces it into the largest groove in the rolls; it is then passed in succession through the other grooves till it attains the required form of the bar.

Shingling.—The old method of shingling the puddle-balls,

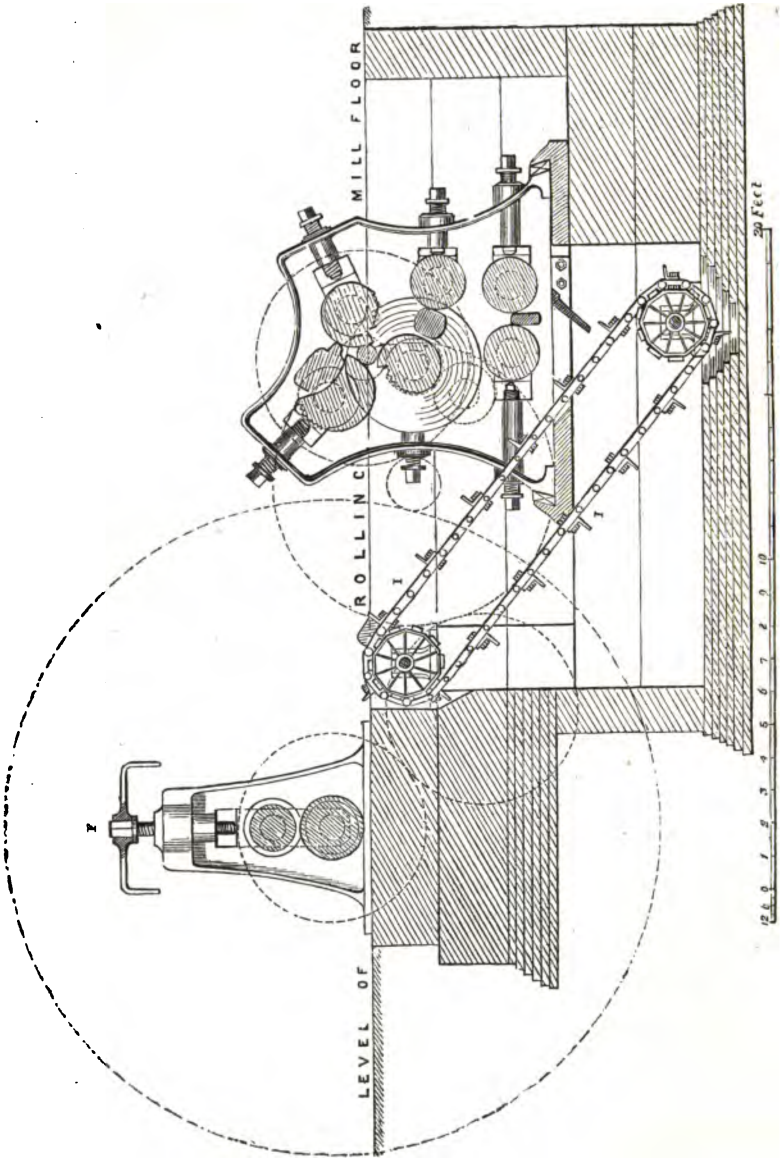

Fig. 28.—Arrangement of Rolling-Mill.

and one still much practised from its simplicity, was to reduce them to shape by a heavy hammer called the forge-hammer or helve, shown in Fig. 29. It consists of a heavy

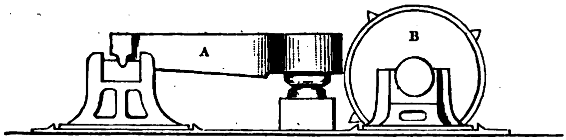

Fig. 29.

mass of iron, A, resting on a pivot at one end, and lifted by projecting cams on a revolving wheel, B, at the other; between these points, and nearer the front, is the anvil, on which the puddler's ball is thrown to receive a rapid succession of strokes, which force out the impurities, and reduce it to a form suitable for insertion between the rolls.

The *squeezer* has also been used for the same purpose, consisting of two massive jaws worked by a lever and crank, between which the ball is moulded by severe pressure to the necessary form. The squeezer is, however, alleged to have the effect of lapping up cinder in the iron to a greater extent

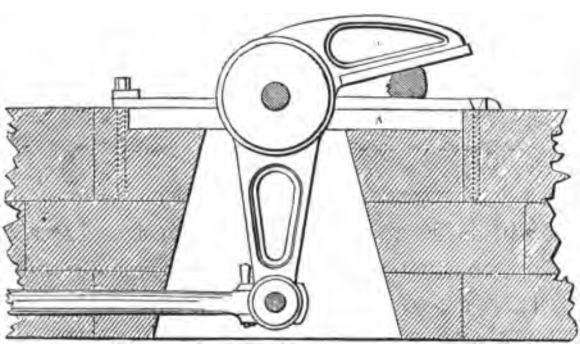

Fig. 30.

than in the case of the forge-hammer. Fig. 30 shows one form of this instrument, sometimes called the Alligator, from

its resemblance to the mouth of that animal, where it will be observed that the puddle-ball is reduced in size by being rolled by the puddler to the back part of the jaws, where the leverage is more powerful as its diameter decreases.

One of the most perfect machines of this class is Brown's bloom-squeezer already alluded to, and shown in Figs. 31, 32, and 33, which sufficiently explain how the heated ball of puddled iron, K, thrown on the top, is gradually compressed between the revolving rollers as it descends, and at last emerges at the bottom, where it is thrown on to the moveable "Jacob's ladder," I, Fig 28, by which it is elevated to the rolls, as already described. This machine effects a considerable saving of

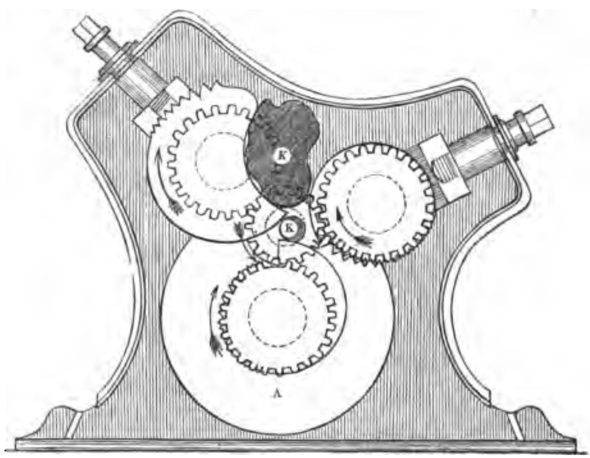

Fig. 31.

time; it will do the work of twelve or fourteen furnaces, and may be kept constantly going as a feeder to one or two pair of rollers. There are two distinct forms of this machine—one as shown in Fig. 31, where the bloom receives only two compressions, and the other, which is much more effective, where it is squeezed four times before it leaves the rolls and falls upon the Jacob's ladder, as exhibited in Figs. 32 and 33.

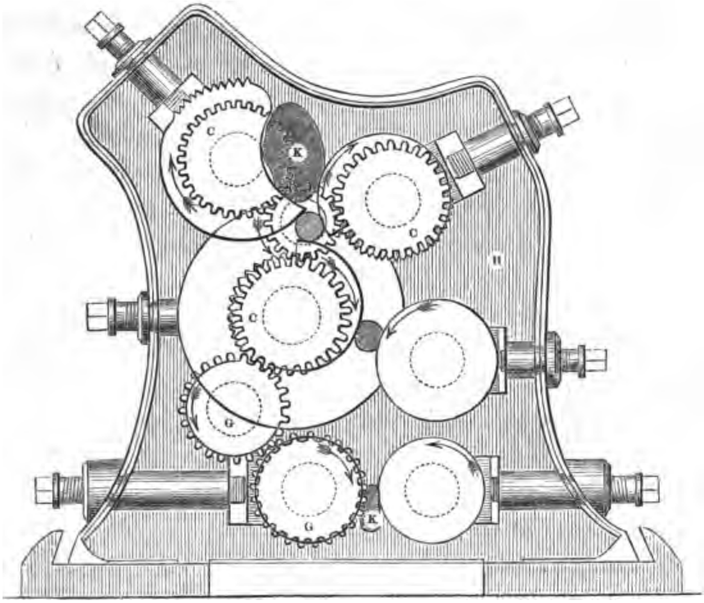

Fig. 32.

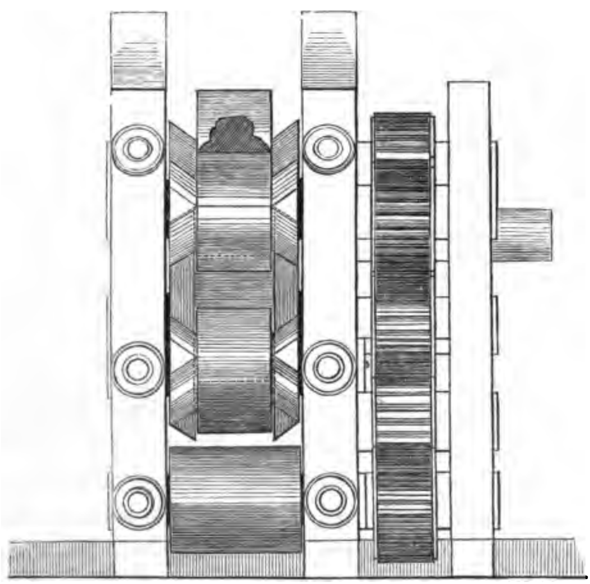

Fig. 33.

There is another machine for preparing the blooms by compression, namely, a table firmly embedded in masonry, as shown at A A, in Fig. 34, with a ledge rising up from it to a height of about two feet, so as to form an open box. Within this is a revolving box C, of a similar character, much smaller than the last, and placed eccentrically in regard to it. The ball or bloom D is placed between the innermost revolving box C and the outer case A A, where the space between them is greatest, and is carried round till it emerges at E, compressed and fit for the rolls.

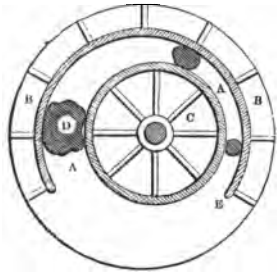

Fig. 34.

The bloom, after leaving the hammer or squeezer, is at once placed in the rolling-mill (Fig. 35). This consists of massive

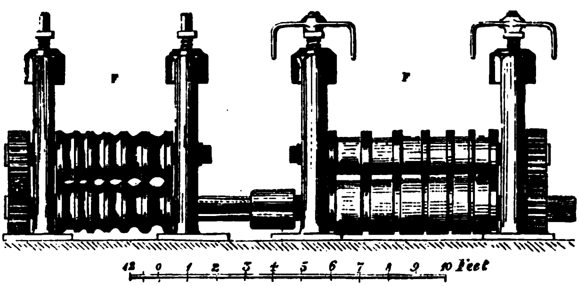

Fig. 35.

grooved rollers connected by tooth pinions, and put in motion by the steam-engine. The rollers are fixed on massive framing, which has to support a prodigious strain, as the bloom is sucked in, and compressed and elongated as it passes through. The bar so formed is passed through a succession of similar grooves, decreasing in size till it is reduced to about four inches wide, three quarters of an inch to an inch thick, and ten or twelve feet in length. In this state it is called a puddle-bar,

and is taken to the shears, cut into pieces, piled into a second bloom, or pile as it is then called, heated in a reverberatory furnace to a welding temperature, brought under the hammer, and a second time rolled. The bars produced by this second process are called merchant-bars; or the bloom may have been rolled into plates; or lastly, instead of being rolled at all, it may have been brought under the steam-hammer and forged into "*uses*," or those variously-shaped masses of wrought-iron which are employed by the engineer and millwright.

Advantages of the Horizontal Engine.—We have stated that the horizontal, non-condensing steam-engine, from its compact form and convenience of handling, is admirably adapted for giving motion to the machinery of ironworks. For this object it is superior to the beam-engine, as its speed can be regulated with the greatest nicety, by opening or shutting the valve, so as to suit all the requirements of the manufacture, under the varied conditions of the pressure of the steam, and the power required for rolling heavy plates or bars, or those of a lighter description. It is also much cheaper in its original cost, and all its parts being fixed upon a large bed-plate, requires a comparatively small amount of masonry to render it solid and secure.

Rolling-Mills.—In regard to the manufacture of the rollers for the puddling, boiler-plate, and merchant train, the greatest care must be observed in the selection of the iron and the mode of casting. In Staffordshire there are roller-makers, but in general the manufacturer casts his own; and as much depends upon the metal, the strongest qualities are carefully selected and mixed with Welsh No. 1 or No. 2, and Staffordshire No. 2. This latter description of iron, when duly prepared, exhibits great tenacity, and is well adapted, either in the first or second melting, for such a purpose. In casting, the moulds are prepared in loam, and when dry are sunk vertically into the pit to a depth of about five feet below the floor. The moulding-

box is surrounded by sand firmly consolidated by beaters, and a second mould or head is placed above it, which receives an additional quantity of iron to supply the space left by shrinking, and keep the roller under pressure until it solidifies, and thus secures a great uniformity and density in the roller. The metal is run into the mould direct from the air-furnace by channels cut in the sand; and immediately the mould is filled, the workman agitates the metal with a rod, in order to consolidate the mass and get rid of any air or gas which may be confined in the metal. This stirring with iron rods is continued till the metal cools to a semifluid state, when it is covered up and allowed slowly to cool and crystallize. This slow rate of cooling is necessary to favour a uniform degree of contraction, as the exterior closes up like a series of hoops round the core of the casting, which is always the most porous and the last to cool. In every casting of this kind, it is essential to avoid unequal contraction; and this cannot be accomplished unless time is given for the arrangement of the particles by a slow process of crystallization. Rollers for boiler-plates and thin sheet-iron are difficult to cast sound, on account of their large size. They are subjected to very great strain, and require to be cast from the most tenacious metals. The bearings or neck should be enlarged, or turned to the shape shown at A A, and the cylindrical part B, for plate-rolls, should be slightly concave; because, when the slab is first passed through the rollers, it comes in contact with a small portion only of the revolving surface. The central parts of the roller thus become highly heated, whilst their extremities are perfectly cool. The consequence is, that the expansion of the roller is greatest in the middle; and unless this be provided for by a concavity in the barrel, the plates become buckled, that is, both warped and uneven in thickness, and, consequently, imperfect and unfit for the purposes of boiler-making. Bar

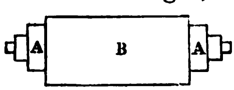

Fig. 36.

rolls are generally cast in chill, and great care is required to prevent the chill penetrating too deep, so as to injure the tenacity of the metal and render it brittle.

There are different kinds of rolling-mills used in the iron manufacture, and they vary considerably in their dimensions, according to the work they have to perform. The first, through which the puddled iron is passed, we have already described as puddling-rolls. There are others for roughing down, which vary from 4 to 5 feet long, and are about 18 inches diameter; those for merchant bars, about 2 feet 6 inches to 3 feet long, and 18 inches in diameter, are in constant use. The boiler-plate and black sheet-iron rolls are generally of large dimensions; some of them for large plates are upwards of 6 feet long and 18 to 21 inches in diameter; these require a powerful engine and the momentum of a large fly-wheel to carry the plate through the rollers; and not unfrequently when thin wide plates have to be rolled, the two combined prove unequal to the task,—and the result is, the plates cool and stick fast in the middle. The greatest care is necessary in rolling plates of this kind, as any neglect of the speed of the engine or the setting of the rolls results in the breakage of the latter, or bringing the former to a complete stand.

The speed of the different kinds of rolling-mills varies according to the work they have to perform. Those for merchant bars make from 60 to 70 revolutions a minute, whilst those of large size, for boiler-plates, are reduced to 28 or 30. Others, such as the finishing and guide rollers, run at from 120 to 400 revolutions a minute. In Staffordshire, where some of the finer kinds of iron are prepared for the manufacture of wire, the rollers are generally made of cast-steel, and run at a high velocity. Such is the ductility of this description of iron, that in passing through a succession of rollers, it will have elongated to ten or fifteen times its original length, and, when completely

finished, will have assumed the form of a strong wire $\frac{3}{8}$ to $\frac{1}{4}$ of an inch in diameter, and 40 to 50 feet in length.

A high temperature is an indispensable condition of success in rolling. The experience of the workman enables him to judge, from the appearance of the furnace, when the pile is at a welding heat, so that, when compressed in the rolls, the particles will unite. Sometimes it is necessary to give a fine polish or skin to the iron as it leaves the rolls; but this can only be done when the iron cools down to a dark-red colour, and by the practised eye of an intelligent workman.

Shearing.—The above operations would still be incomplete, unless the ironmaster had means of cutting the bars and plates to any required size and shape. The machinery for this purpose has of late been brought to a high degree of perfection, both in regard to power and precision.

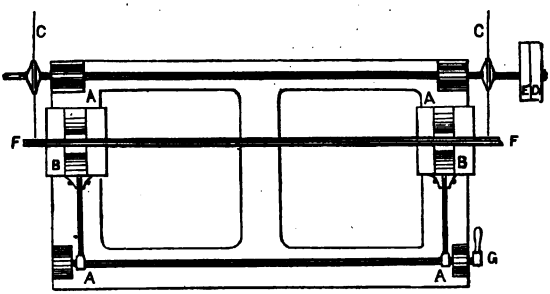

Fig. 37.

The circular saw has been successfully applied for squaring and cutting the larger descriptions of bars, and does its work, particularly in railway bars, with almost mathematical precision. This machine consists of a cast-iron frame or bed A A, Fig. 37, bolted down to a solid foundation, on the ends of which slide two frames, B B, to support the bar to be cut. The two circular saws or cutters, C C, are driven by straps passing over the pulleys D E, and rotate at the rate of 800 to 1000 revolutions per minute. The machine is set in motion by trans-

ferring the straps from the loose pulley D to the fast pulley E; and as soon as the required speed is attained, the frame B B is carried forward, and the bar F F along with it, by a lever G or eccentric motion, till the bar is cut through. The rate of cutting or pressure upon the saws may be regulated either by hand or weight; care must however be taken not to allow the saws to become too hot, and this is provided against by running them in a trough of water. By this process it is evident that the bar must always be cut square at the ends and correctly to the same length. We are informed that the circular saw for cutting railway bars is frequently driven by the Eolipile or Hero's engine, by which a speed of 2000 revolutions a minute may be attained without the intervention of multiplying gearing.

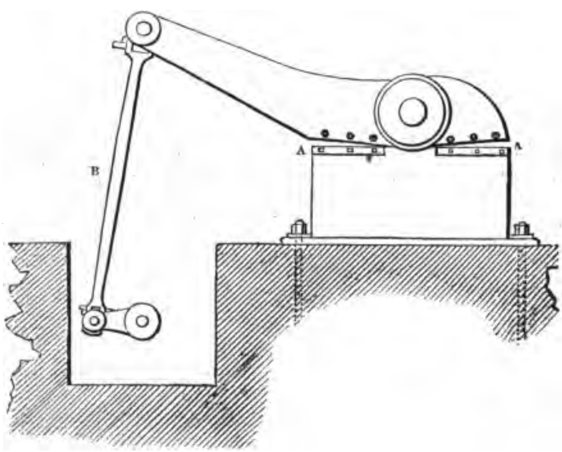

Fig. 38.

A great variety of shears are used for cutting iron, some driven by cams or eccentrics, and some by connecting rods and a crank on the revolving shaft. In large ironworks it is necessary to have two or three kinds, some for cutting up scrap iron and bars for piling, and others for boiler-plates. Of the first we may notice two: one, shown in Fig. 38, cuts on

both sides at A A, and is driven by a crank and connecting-rod B. This machine is chiefly used for cutting puddled bars from the puddling-rolls, or any work required for shingling.

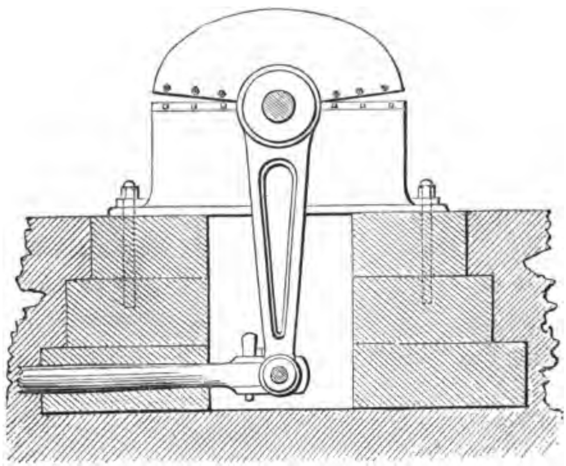

Fig. 39.

The next machine, Fig. 39, receives motion in the same manner, and also cuts on both sides, the cutters being fixed on the lever and moving with it. This is used for the same purpose as the last, and likewise for cutting scrap iron. These machines are extensively used in the manufacture of iron; and before the introduction of the plate shears, they were used, with some modifications, to cut boiler-plates, but the work was very imperfectly executed.

The demand for plates of large dimemsions and greatly increased weight, such as those for the front and tube plates of locomotive and marine boilers, and those for tubular and plate bridges, created great difficulties, not only in piling, heating, and rolling, but also in cutting the plates accurately to the required size. To meet these demands, and more particularly for the manufacture of the large plates employed in the cellular top of the Britannia and Conway tubular bridges,

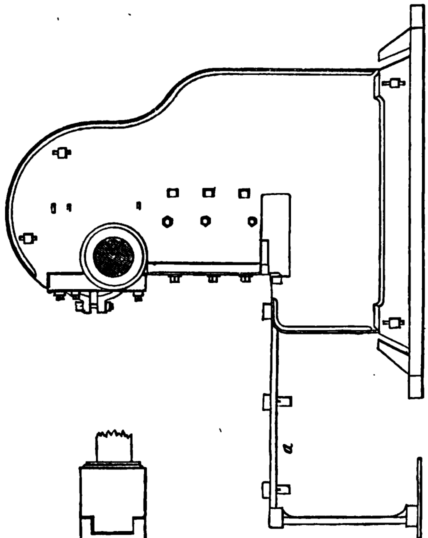

Fig. 41.—Side View.

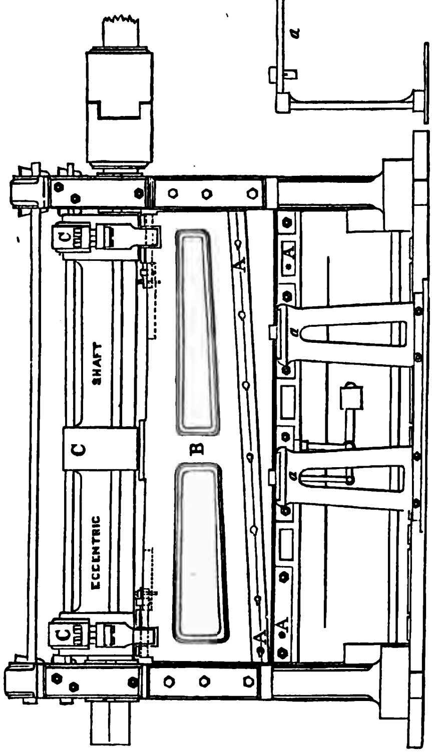

Fig. 40.—Elevation.

Messrs. G. B. Thorneycroft aud Co. constructed a large shearing machine which cut upwards of 10 feet at one stroke. These shears have now come into general use, and are of great importance, on account of the accuracy with which they cut plates of large dimensions square and even. Figs. 40 and 41 represent this machine; *a a a* is the standard and table on which the plate is fixed. This table slides forward at right angles to the shears or cutters A A A*A*. The top cutter descends by the action of three eccentrics *c c c*, which press upon the top of the frame B as it revolves, and force it down; and by one stroke, the knife A A cuts through the whole length of the plate, perfectly clean

and straight. The plate is then reversed, the newly-cut edge being held against the slopes, and the sliding frame again moved forward to the required width of the plate, when another stroke cuts the other side as before. The rapidity with which the plates are cut is another advantage of this machine, as great as the precision of its cut; and when the immense quantity of plates daily produced at Messrs. Thorneycroft and Co.'s works are considered, its importance becomes evident.

At the Paris Universal Exhibition of last year (1855), a plate-cutting machine was exhibited, from the United States of America, which appears to effect the same operation as Messrs. Thorneycroft and Co.'s. It consists of a strong cast-iron frame, nine or ten feet wide, having inserted along its face a steel plate, on which the iron to be cut rests, and is held firmly by a faller, which descends on the upper side of the plate. On the same side of the frame a revolving steel cutter, about nine inches in diameter, traverses the whole length of the frame, and in its passage cuts the plate, by compression, in a perfectly straight line, corresponding with the steel edge below. Cutting and shaving plates by a revolving disc has been long in use, but the traversing motion in this machine is certainly new, and its application very creditable to the ingenuity of the inventor. The travelling cutter, which requires great power when cutting thick plates, is driven by a strap over a pulley at one end of the machine, and looking at the work it has to perform, and the complexity of its parts, we should consider it less effective and more liable to derangement than the simple and powerful machine of Messrs. Thorneycroft.

General Summary.—Having thus traced the processes for the conversion of crude into malleable iron, and the machinery employed, it only remains to give a general summary of the whole. As regards the arrangement of large ironworks, the

general principle should be for the machinery to be classed and fixed in the order of the different processes, so that the products of one machine should pass at once to the next, and, in fact, the crude iron should be received at one end, and, having passed through all the processes, delivered at the other in the manufactured state.

The crude iron from the smelting-furnace is either refined and puddled, or subjected to the boiling process, to get rid of the combined carbon, and render the iron malleable; it is then shingled by the forge-hammer, by the "Alligator," by Brown's squeezer, or by one of the other machines which have been invented for this purpose. It is then at once passed through the puddling-rolls, where it is reduced to the form of a flat bar, and is then cut into convenient lengths by the shears. These pieces are again piled or faggoted together into convenient heaps, and re-heated in the furnace. As soon as a faggot thus prepared has been heated to the welding temperature, it is passed through the roughing-rolls to reduce it to the form of a bar, and then through the finishing-rolls, where the required form and size is given to it—either round or square bars, plates, etc. These are straightened and sheared to the required sizes, and are then ready for delivery. In most large works all these operations are carried on simultaneously with the smelting process, and in some with extensive mining operations for procuring the coal, ore, and limestone required to supply a production of several thousand tons of manufactured iron per month.

CHAPTER VII.

THE FORGE.

THE forging of iron has entered, of late years, so largely into the constructive arts, that the manufactures, however perfect in the rolling-mill, would be very imperfect indeed without the forge. To the discussion of this part of the subject there are many inducements, and we cannot but wonder at the many devices, and the numerous contrivances which present themselves for the attainment of the operations of the forge. In effecting these objects, Mr. Nasmyth's steam-hammer is evidently the most effective, and to that instrument we are indebted for the welding of large masses of iron upon a scale previously unknown to the workers in that metal.

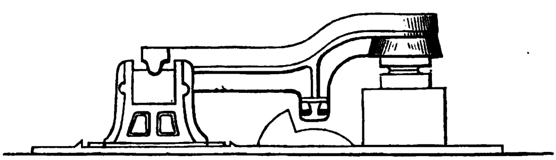

Fig. 42.

The old form of forge-hammer, or at least the form most suitable for heavy forgings, was that known as the belly-helve, and is shown in Fig. 42. In this hammer the wheel carrying the cam by which it is lifted is placed between the anvil and the fulcrum. The action is simple and the hammer is effective, but there is no provision for altering the intensity of the blow, whatever the nature of the work which had to

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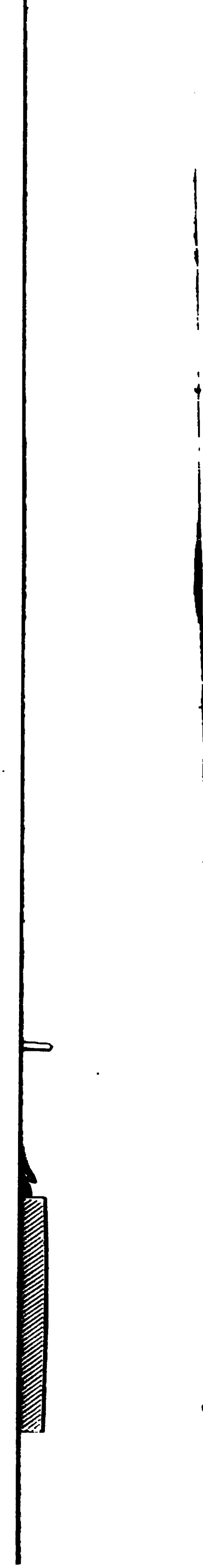


be accomplished. For heavy forgings, scrap iron, cut up into small pieces by the shears, is usually employed. It is placed in a revolving hexagonal drum, by which the pieces knock each other about, and are cleaned from rust; and being piled and faggoted into convenient-sized masses of one or two hundredweight, are placed in a re-heating or piling furnace, similar to the reverberatory furnace employed in puddling. When they have reached a welding heat, they are placed under the helve, and united into a bloom or slab. These slabs form the masses of which larger forgings are built up. These, when too large to be handled by the forgeman, are supported by a crane beside the hammer, so that they can be turned over and manipulated with the greatest ease.

Mr. Nasmyth took out his patent for the invention of a hammer, which has superseded all preceding forge-tools in the better descriptions of work, in 1833; and from that time up to the present, it has maintained its ground against every innovation, and has performed an important duty in almost every well-regulated work in Europe. It consists of an inverted cylinder D, Figs. 43 and 44, through which the piston-rod E passes, attached to the hammer-block F by means of bars and cross-key *k*, which press upon an elastic packing, to soften the blow of the hammer, which in heavy forgings and heavy blows operated severely upon the piston-rod. The hammer-block F F is guided in its vertical descent by two planed guides or projections, extending the length of the side-standards A A, between which the hammer-block slides. The attendant gives motion to the hammer by admitting steam from the boiler to act upon the under side of the piston, by moving the regulator I by the handle *d*. The length of stroke is regulated by increasing or diminishing the distance between the cam N and the valve lever O *o*, by turning the screws P and U by the bevil wheels *q q*. The lever O *o* operates by the cam N coming in contact with the

roller *o*. As soon as this contact takes place, the further admission of steam is not only arrested, but its escape is at the same time effected, and the hammer, left unsupported, descends by its gravity upon the work on the anvil with an energy due to the height of the fall. From this description it will be seen that the movement of the roller *o* causes the shoulder of the rod P to get under the point of the trigger-catch *u*; the valve is by these means kept closed till the whole force of the blow is struck. The instant the operation is effected, the concussion of the hammer causes the latch X to knock off the point of the trigger from the shoulder on the valve-rod P, by means of the bent lever *s v*; and the instant this is accomplished, the valve is re-opened to admit the steam below the piston, by the pressure of steam on the upper side of the small piston in the cylinder M, forcing down the valve-rod, which in this respect is the active agent for opening the valve.

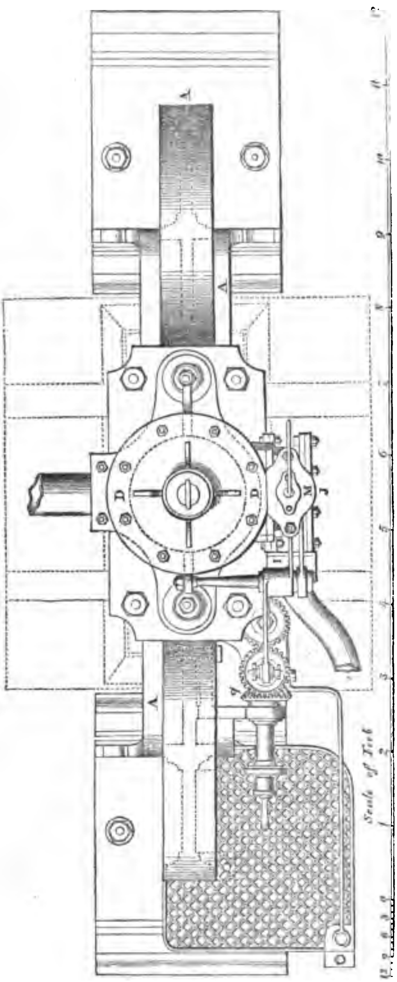


Fig. 44.—Plan.

To arrest the motion of the hammer, it is only necessary to shut the steam-valve. During the process of forging, it is, however, desirable to give time between the blows, to enable the workman to turn and shift his work on the anvil; and to effect this reduced motion, the trigger U is held back from the shoulder of the valve-rod P by the handle *y*, which at the same instant opens the valve in the case J, and thus the action of the steam in the cylinder D retards the downward motion of the hammer. The result of these changes is an easy descent of the hammer, which vibrates up and down without touching the anvil, but ready for blows of any severity the instant the trigger is elevated above the shoulder of the valve-lever P. From this description it will appear evident that Mr. Nasmyth's invention is one of the most important that has occurred in the art of forging iron. It has given an impetus to the manufacture, and affords facilities for the welding of large blocks of malleable iron that could not be accomplished by the tilt and helve hammers formerly in use; and we have only to instance the forging of the sternposts and cutwaters of iron ships; the paddle-wheel and screw-shafts of our ocean-steamers, some of them weighing upwards of 20 tons, to appreciate the value as well as the intensity of action of the steam-hammer.

Various modifications of Nasmyth's hammer are now in use. In Condie's, which has much merit, the piston-rod is stationary, and the cylinder moves, carrying the block of metal forming the hammer on its bottom. The piston and piston-rod are suspended from the top of the framing, and the steam is admitted through the hollow piston-rod, and lifts the hammer by pressing against the top cylinder cover. In Morrison's, the piston-rod is made very large, so as to form the hammer, and slides through a gland in the fixed cylinder both at top and bottom. In some cases, as for anchor-forging, where the cast-iron standards are in the way, they are dispensed with, and the cylinder is supported on wrought-iron

beams spanning the smithy, so as to leave a free space all round the anvil. Various changes in the valve gearing have been effected by Mr. Naylor and others, and a lighter description of hammer has been introduced by Mr. Rigby, in which the steam acts on both sides of the piston, urging it in its descent as well as lifting it after the blow is struck, by which means great rapidity of action is attained. In Mr. Naylor's hammer, also, which has been made of large size, the advantage of admitting steam to both sides of the piston has been obtained, the downward stroke being increased in momentum, and the number of strokes in a given time augmented. With small hammers acting on this principle, 250 blows per minute have been obtained.

In addition to the machinery of the forge, the V anvil, Fig. 45, the natural offspring of the steam-hammer, came into existence from the same fertile source. It is chiefly employed for forging round bars and shafts, and may be thus described,—A being a section of the round bar or shaft to be forged, B the anvil-block, and C the hammer. From this it is obvious that, in place of the old plan, where the work is forged upon flat surfaces, as shown in Fig. 46, and where the blows are diverging, the effect of the V anvil is a converging action, thus consolidating the mass, and enabling the forger to retain his work directly under the centre of the hammer. This is the more strikingly apparent, as the blows of a hammer upon a round shaft have the effect of causing the mass to assume the elliptical form, forcing out the sides as at A A at every successive blow; and this again, when turned, produces a spongy, porous centre, as shown in Fig. 47. This

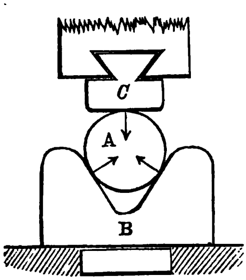


Fig. 45.

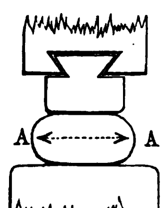


Fig. 46.

process is, however, more clearly exemplified in Ryder's forging-machines, where all the anvils are of the V form, for the forging of spindles, round bars, and bolts.

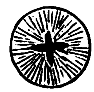


Fig. 47.

The most remarbable instance of a large forging, and one which will serve as an example of the best methods of piling, etc., is the large wrought-iron gun, weighing before boring 25 tons. Mr. Clay, under whose direction it was produced at the Mersey Works, Liverpool, gives the following account of the method of manufacture:—"It was built in seven distinct layers or slabs, and the forging occupied seven weeks: nor will this time seem unreasonable, when its dimensions and weight are considered. The first operation was to prepare a core of suitable dimensions, and nearly the whole length of the gun. This was done by taking a number of rolled bars, about 6 feet in length, welding them together, and drawing them out till the proper length was attained. A series of V-shaped bars were now packed round the core (Fig. 48), the whole mass heated in a reverberatory furnace, and forged under the largest belly-helve hammer. Another series of bars were now packed on, and the mass was heated again and worked perfectly sound. Another longitudinal series of bars were still required over the whole length of the forging, which were added, and the mass now presented a forging about 15 feet in length and 32 inches in diameter, but requiring to be augmented to 44 inches at the breech, tapering down to 27 inches at the muzzle. This was accomplished by two layers of iron placed in such a manner as to

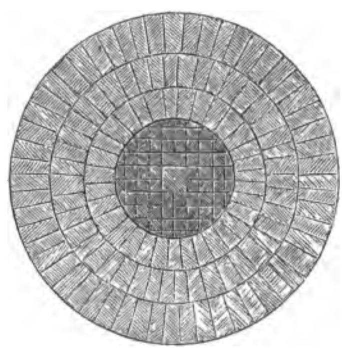
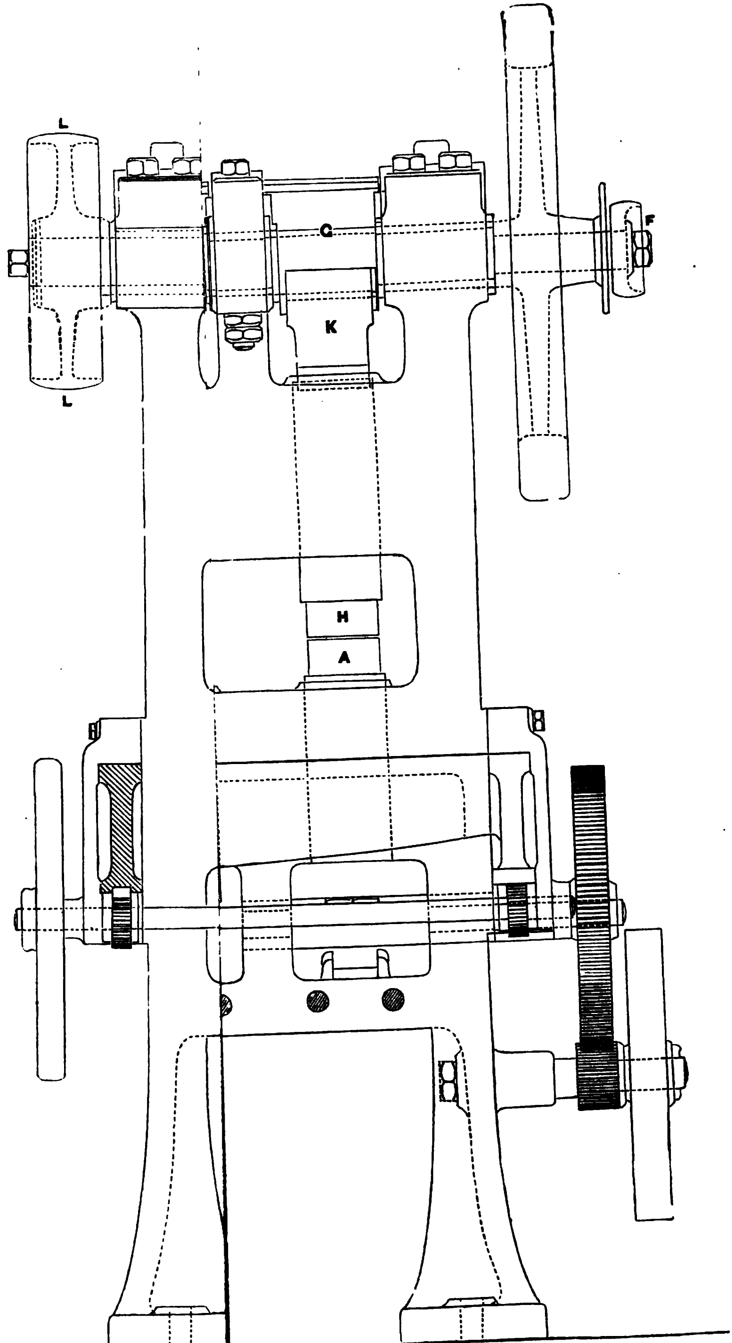


Fig. 48.

resemble hoops laid at right angles to the axis of the mass; and after two more heatings, and careful welding, the forging of the gun was completed."

The next important addition to the implements of the forge is Mr. Ryder's machine, patented some years since, for forging small articles, which, on account of the rapidity and precision of its operations, demands a notice in passing. It consists essentially of a series of small anvils about three inches square, supported from below by large screws passing through the frame of the machine. This screw was employed in order that the distance between the hammer and anvil might be accurately adjusted. Between the screw and the anvil, a stuffing of cork is introduced to deaden the effect of the blow. The hammers are arranged over the anvils, and slide up and down in the frame of the machine. The blow is effected by the revolution of an eccentric, acting by means of a cradle on the hammer-head—the hammer, however, being lifted again by a strong spiral spring. The hammers make about 700 strokes a minute. At the side of the machine is a cutter or shears worked by a long lever; with this the articles are cut to the required length as they are finished.

Figs. 49 and 50 represent this machine as improved by Messrs. Platt Brothers of Oldham. AAAA are the anvils supported on a wedge B, instead of the screw, as in Ryder's. This substitution was made because the blows of the hammer tore off the threads of the screw, and the machine soon got out of order. The distance between the hammer and anvil is regulated by forcing forwards the wedge B by the rack and pinion C. The cork was then found insufficient as a stuffing, and an immensely strong spring D was substituted. This spring is formed of a band of steel $1\frac{3}{4}$ inches broad, and $\frac{5}{8}$ thick, coiled in a close spiral 2 inches in diameter, and $6\frac{1}{2}$ long. It answers its purpose admirably. The hammers are shewn at HHHH, supported by springs, one of which is seen



chine (p. 138).

in the section at E. The eccentrics GGGG, driven by the shaft FF, in their revolution force down the cradles KKKK,

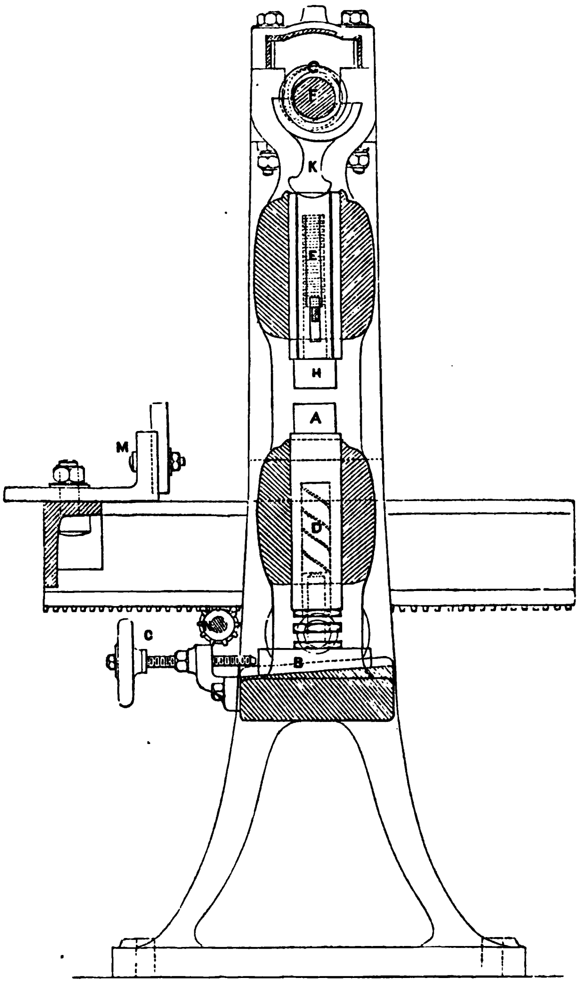


Fig. 50.—End Section.

which in their turn act on the tops of the hammers; the springs E keep the hammer-head always in contact with the cradles KK. The shaft FF is driven by a strap on the pulley

LL. It is evident that, by the revolution of the shaft, the eccentric forces down the hammer, and then allows the spring to lift it again; the rapidity of the strokes is only limited by the power of the spring E to keep the hammer in contact with the cradle; if the eccentric revolves too fast, a violent jerking motion is produced. In Mr. Ryder's machine, 700 strokes a minute was the maximum; but Messrs. Platt Brothers, by increasing the strength of the spring, run as high as 1100. A pair of knife edges, worked by the machine itself, has also been substituted for the hand-shears. These perform the work more rapidly and accurately than before, and leave the workman more at liberty. Dies are let into the surfaces of the hammers and anvils, which shape the iron as required.

The rapidity with which this machine executes all kinds of intricate work is truly remarkable; for instance, a bar about $2\frac{3}{4} \times 2\frac{1}{4}$ inches, will be reduced to $1\frac{1}{4} \times 10$ inches, and cut off in a minute. Set screws, bolts, spindles, and all kinds of small work, are produced at the same rate. Its precision is very effective; the articles are almost as true as if turned in a lathe, and very accurate as to size and weight. Other machines, called "lifts," have been, and continue to be, used for forging a variety of forms and "*uses;*" but as these partake more or less of the principle employed in Ryder's machine, it will not be necessary to furnish further examples.

In conclusion, we may observe that the facilities afforded by the present age for the forging of malleable iron are without a parallel in the history of that material. Every known resource has been adopted, and every contrivance and device has been employed to meet the demands of a large and an intricate trade; and looking at the present resources of the country, and the admirable mechanical contrivances for the conversion of crude iron into the malleable state, it assuredly is not unreasonable to look forward to still greater improvements in the manipulations of the forge.

CHAPTER VIII.

MR. BESSEMER'S PROCESS.

Since the above was written, an apparently new light has been thrown on the conversion of iron, by a paper read by Mr. H. Bessemer at the last meeting of the British Association for the Advancement of Science, held at Cheltenham in August last (1856). In this paper the author announces to the world the discovery of an entirely new system of operations for the manufacture of malleable iron and steel. The crude metal is converted, by one simple process, directly as it comes from the blast-furnace. We should detract from its clearness did we attempt to curtail the lucid description in which Mr. Bessemer has recommended his invention to the manufacturers and the public; we therefore give the account in his own words:—

Mr. Bessemer states that "for the last two years his attention has been almost exclusively directed to the manufacture of malleable iron and steel, in which, however, he had made but little progress until within the last eight or nine months. The constant pulling down and rebuilding of furnaces, and the toil of daily experiments with large charges of iron, had begun to exhaust his patience; but the numerous observations he had made during this very unpromising period all tended to confirm an entirely new view of the subject, which at that time forced itself upon his attention—viz., that he could produce a much more intense heat, without any furnace or fuel, than could be obtained by either of the

modifications he had used; and consequently, that he should not only avoid the injurious action of mineral fuel on the iron under operation, but that he would, at the same time, avoid also the expense of the fuel. Some preliminary trials were made on from 10 lbs. to 20 lbs. of iron; and although the process was fraught with considerable difficulty, it exhibited such unmistakable signs of success, as to induce him at once to put up an apparatus capable of converting about 7 cwt. of crude pig-iron into malleable iron in thirty minutes. With such masses of metal to operate on, the difficulties which beset the small laboratory experiments of 10 lbs. entirely disappeared.

"On this new field of inquiry, he set out with the assumption that crude iron contains about 5 per cent of carbon; that carbon cannot exist at a white heat in the presence of oxygen without uniting therewith, and producing combustion; that such combustion would proceed with a rapidity dependent on the amount of surface of carbon exposed; and lastly, that the temperature which the metal would acquire would be also dependent on the rapidity with which the oxygen and carbon were made to combine, and consequently, that it was only necessary to bring the oxygen and carbon together in such a manner that a vast surface should be exposed to their mutual action, in order to produce a temperature hitherto unattainable in our largest furnaces.

"With a view of testing practically this theory, he constructed a cylindrical vessel of three feet in diameter, and five feet in height, somewhat like an ordinary cupola furnace, the interior of which was lined with fire-bricks; and at about two inches from the bottom of it he inserted five tuyere pipes, the nozzles of which were formed of well-burnt fire-clay, the orifice of each tuyere being about three-eighths of an inch in diameter. They were put into the brick lining from the outside, so as to admit of their removal and renewal in a few minutes, when they were worn out.

"At one side of the vessel, about half-way up from the bottom, there was a hole made for running in the crude metal, and in the opposite side was a tap-hole, stopped with loam, by means of which the iron was run out at the end of the process. In practice, this converting vessel may be made of any convenient size, but he prefers that it should not hold less than one or more than five tons of fluid iron at each charge. The vessel should be placed so near to the blast-furnace so as to allow the iron to flow along a gutter into it; a small blast-cylinder is required, capable of compressing air to about 8 lbs. or 10 lbs. per square inch. A communication having been made between it and the tuyeres before mentioned, the converting vessel will be in a condition to commence work; it will, however, on the occasion of its first being used, after relining with fire-bricks, be necessary to make a fire in the interior with a few baskets of coke, so as to dry the brick-work and heat up the vessel for the first operation, after which the fire is to be carefully raked out at the tapping-hole, which is again to be made good with loam. The vessel will then be in readiness to commence work, and may be so continued until the brick lining, in the course of time, is worn away, and a new lining is required.

"The tuyeres, as before stated, were situated nearly close to the bottom of the vessel; the fluid metal therefore rose some eighteen inches or two feet above them. It was therefore necessary, in order to prevent the metal from entering the tuyere holes, to turn on the blast before allowing the fluid crude iron to run into the vessel from the blast-furnace. This having been done, and the fluid iron run in, a rapid boiling up of the metal was heard going on within the vessel, the iron being tossed violently about, and dashed from side to side, shaking the vessel by the force with which it moved. Flame, accompanied by a few bright sparks, immediately issued from the throat of the converting vessel. This state

of things lasted for about fifteen or twenty minutes, during which time the oxygen in the atmospheric air combined with the carbon contained in the iron, producing carbonic acid gas, and at the same time evolving a powerful heat.

"Now, as this heat is generated in the interior of, and is diffused in innumerable fiery bubbles throughout the whole fluid mass, the vessel absorbs the greater part of it, and its temperature becomes immensely increased; and by the expiration of the fifteen or twenty minutes before named, that part of the carbon which appears mechanically mixed and diffused through the crude iron has been entirely consumed. The temperature, however, is so high, that the chemically combined carbon now begins to separate from the metal, as is at once indicated by an immense increase in the volume of flame rushing out of the throat of the vessel. The metal in the vessel now rises several inches above its natural level, and a light frothy slag makes its appearance, and is thrown out in large foam-like masses.

"This violent eruption of cinder generally lasts about five or six minutes, when all further appearance of it ceases, a steady and powerful flame replacing the shower of sparks and cinders which always accompanies the boil. The rapid union of carbon and oxygen which thus takes place adds still further to the temperature of the metal, while the diminished quantity of carbon present allows a part of the oxygen to combine with the iron, which undergoes a combustion and is converted into an oxide. At the excessive temperature that the metal has now acquired, the oxide, as soon as formed, undergoes fusion, and forms a powerful solvent of those earthy bases that are associated with the iron. The violent ebullition which is going on mixes most intimately the scoriæ and metal, every part of which is thus brought into contact with the fluid oxide, which will thus wash and cleanse the metal most thoroughly from the silica and other earthy bases, which are combined with the crude iron; while the sulphur and other

volatile matters, which cling so tenaciously to iron at ordinary temperatures, are driven off, the sulphur combining with the oxygen, and forming sulphurous acid gas. The loss in weight of crude iron during its conversion into an ingot of malleable iron, was found, on a mean of four experiments, to be 12½ per cent, to which will have to be added the loss of metal in the finishing-rolls. This will make the entire loss probably not less than 18 per cent, instead of about 28 per cent, which is the loss on the present system. A large portion of this metal is, however, recoverable by treating with carbonaceous gases the rich oxides thrown out of the furnace during the boil. These slags are found to contain innumerable small grains of metallic iron, which are mechanically held in suspension in the slags, and may be easily recovered.

"It has already been stated that after the boil has taken place, a steady and powerful flame succeeds, which continues without any change for about ten minutes, when it rapidly falls off. As soon as this diminution of flame is apparent, the workman knows that the process is completed, and that the crude iron has been converted into pure malleable iron, which he will form into ingots of any suitable size and shape, by simply opening the tap-hole of the converting vessel, and allowing the fluid malleable iron to flow into the iron ingot-moulds placed there to receive it. The masses of iron thus formed will be perfectly free from any admixture of cinder, oxide, or other extraneous matters, and will be far more pure, and in a forwarder state of manufacture, than a pile formed of ordinary puddle-bars. And thus, by a single process, requiring no manipulation or particular skill, and with only one workman, from three to five tons of crude iron pass into the condition of several piles of malleable iron, in from thirty to thirty-five minutes, with the expenditure of about one-third part the blast now used in a finery furnace with an equal charge of iron, and with the consumption of no other fuel than is contained in the crude iron.

"To those who are best acquainted with the nature of fluid iron, it may be a matter of surprise that a blast of cold air forced into melted crude iron is capable of raising its temperature to such a degree as to retain it in a perfect state of fluidity, after it has lost all its carbon, and is in the condition of malleable iron, which, in the highest heat of our forges, only becomes a pasty mass. But such is the excessive temperature that may be arrived at, with a properly shaped converting vessel, and a judicious distribution of the blast, that not only may the fluidity of the metal be retained, but so much surplus heat can be created as to remelt the crop ends, ingot runners, and other scrap, that is made throughout the process, and thus bring them, without labour or fuel, into ingots of a quality equal to the rest of the charge of new metal. For this purpose, a small arched chamber is formed immediately over the throat of the converting vessel, somewhat like the tunnel-head of the blast-furnace. This chamber has two or more openings in the sides of it, and its floor is made to slope downwards to the throat. As soon as a charge of fluid malleable iron has been drawn off from the converting vessel, the workman will take the scrap intended to be worked into the next charge, and proceed to introduce the several pieces into the small chamber, piling them up round the opening of the throat. When this is done, he will run in his charge of crude metal, and again commence the process. By the time the boil commences, the bar ends or other scrap will have acquired a white heat, and by the time it is over, most of them will have melted and run down into the charge. Any pieces, however, that remain, may then be pushed in by the workman, and by the time the process is completed, they will all be melted and intimately combined with the rest of the charge; so that all scrap-iron, whether cast or malleable, may thus be used up without any loss or expense. As an example of the power that iron has of generating heat in this

process, Mr. Bessemer mentions that when trying how small a set of tuyeres could be used, the size he had chosen proved too small, and after blowing into the metal for one hour and three-quarters, he could not get up heat enough with them to bring on the boil. The experiment was therefore discontinued, during which time two-thirds of the metal solidified, and the rest was run off. A larger set of tuyere-pipes were then put in, and a fresh charge of fluid iron run into the vessel, which had the effect of entirely remelting the former charge; and when the whole was tapped out it exhibited, as usual, that intense and dazzling brightness peculiar to the electric light.

"To persons conversant with the manufacture of iron, it will be at once apparent that the ingots of malleable metal which are produced by this process, will have no hard or steely parts, such as are found in puddled iron, requiring a great amount of rolling to blend them with the general mass, nor will such ingots require an excess of rolling to expel the cinder from the interior of the mass, since none can exist in the ingot, which is pure and perfectly homogeneous throughout, and hence requires only as much rolling as is necessary for the development of fibre; it therefore follows that instead of forming a merchant-bar or rail by the union of a number of separate pieces welded together, it will be far more simple, and less expensive, to make several bars or rails from a single ingot; doubtless this would have been done long ago had not the whole process been limited by the size of the ball which the puddler could make.

"The facility which the new process affords, of making large masses, will enable the manufacturer to produce bars that, on the old mode of working, it was impossible to obtain; while, at the same time, it admits of the use of some powerful machinery, whereby a great deal of labour will be saved, and the process be greatly expedited. Mr. Bessemer merely mentions this in passing, without entering into

details, as the patents he has obtained for improvements in this branch of the manufacture are not yet specified. He next points out the perfectly homogeneous character of cast-steel —its freedom from sand cracks and flaws—and its greater cohesive force and elasticity, compared with the blister-steel from which it is made, qualities which it derives solely from its fusion and formation into ingots—all of which properties malleable iron acquires in like manner, by its fusion and formation into ingots in the new process. Nor must it be forgotten that no amount of rolling will give to blistered steel (although formed of rolled bars) the same homogeneous character that cast-steel acquires, by a mere extension of the ingot to some ten or twelve times its original length.

"One of the most important facts connected with the new system of manufacturing malleable iron is, that all the iron so produced will be of the quality known as charcoal-iron—not that any charcoal is used in its manufacture, but because the whole of the processes following the smelting of it are conducted entirely without contact with, or the use of, any mineral fuel; the iron resulting therefrom will, in consequence, be perfectly free from those injurious properties which that description of fuel never fails to impart to iron that is brought under its influence. At the same time, this system of manufacturing malleable iron offers extraordinary facility for making large shafts, cranks, and other heavy masses; it will be obvious that any weight of metal that can be founded in ordinary cast-iron, by the means at present at our disposal, may also be founded in molten malleable iron, and be wrought into the forms and shapes required, provided that we increase the size and power of our machinery to the extent necessary to deal with such large masses of metal. A few minutes' reflection will show the great anomaly presented by the scale on which the processes of iron-making are at present carried on. The little furnaces originally used for smelting ore have,

from time to time, increased in size, until they have assumed colossal proportions, and are made to operate on 200 or 300 tons of material at a time, giving out 10 tons of fluid metal at a single run. The manufacturer has thus gone on increasing the size of his smelting-furnaces, adapting to their use the blast-apparatus of the requisite proportions, and has by this means lessened the cost of production, in every way ensuring a cheapness and uniformity of production that could never have been secured by a multiplicity of small furnaces. While the manufacturer has shown himself fully alive to these advantages, he has still been under the necessity of leaving the succeeding operations to be carried out on a scale wholly at variance with the principles he has found so advantageous in the smelting department. It is true that, hitherto, no better method was known than the puddling process, in which from 4 cwts. to 5 cwts. of iron is all that can be operated upon at a time, and even this small quantity is divided into homœopathic doses of some 70 lbs. or 80 lbs., each of which is moulded and fashioned by human labour, carefully watched and tended in the furnace, and removed therefrom, one at a time, to be carefully manipulated and squeezed into form. Considering the vast extent of the manufacture, and the gigantic scale on which the early stages of its progress are conducted, it is astonishing that no effort should have been made to raise the after processes somewhat nearer to a level commensurate with the preceding ones, and thus rescue the trade from the trammels which have so long surrounded it.

"Mr. Bessemer then adverts to another important feature of the new process, the production of what he calls semi-steel. At the stage of the process immediately following the boil, the whole of the crude iron has passed into the condition of cast-steel of ordinary quality. By the continuation of the process the steel so produced gradually loses its small remaining portion of carbon, and passes successively

from hard to soft steel, and from softened steel to steely iron, and eventually to very soft iron; hence, at a certain period of the process, any quality may be obtained: there is one in particular, which, by way of distinction, he calls semi-steel, being in hardness about midway between ordinary cast-steel and soft malleable iron. This metal possesses the advantage of much greater tensile strength than soft iron; it is also more elastic, and does not readily take a permanent set, while it is much harder, and it is not worn or indented so easily as soft iron. At the same time it is not so brittle or hard to work as ordinary cast-steel. These qualities render it eminently well adapted to purposes where lightness and strength are especially required, or where there is much wear, as in the case of railway bars, which, from their softness and lamellar texture, soon become destroyed. The cost of semi-steel will be a fraction less than iron, because the loss of metal that takes place by oxidation in the converting vessel is about 2½ per cent less than it is with iron; but as it is a little more difficult to roll, its cost per ton may fairly be considered to be the same as iron. As its tensile strength is some 30 or 40 per cent greater than bar-iron, it follows that for most purposes a much less weight of metal may be used, so that taken in that way the semi-steel will form a much cheaper metal than any we are at present acquainted with.

"In conclusion, Mr. Bessemer observes that the facts he has discovered have not been elicited by mere laboratory experiments, but have been the result of operations on a scale nearly twice as great as is pursued in the largest ironworks, the experimental apparatus converting 7 cwts. in thirty minutes, while the ordinary puddling-furnace makes only 4½ cwts. in two hours, which is made into six separate balls; while the ingots or blooms are smooth even prisms ten inches square by thirty inches in length, weighing about as much as ten ordinary puddle-balls."

Mr. Bessemer's first patent, in reference to this process, was taken out in 1855, and claimed improvements in the manufacture of cast-steel, consisting of the forcing of currents of air or of steam into and amongst the molten crude iron, or of remelted pig or refined iron, until the metal so treated is rendered malleable and has acquired other properties common to cast-steel. A second patent in the same year claimed the application of the same process to refining iron previous to puddling, or by preference the conversion of the crude iron by a single process, and casting it into ingots suitable for rolling into bar-iron or plates. In February 1856, further details of the process are described in a patent, the object of which is stated to be the conversion of molten crude iron or remelted pig or finery iron into steel, or malleable iron, without the use of fuel for reheating or continuing to heat the crude molten metal, such conversion being effected by forcing into and among the molten mass currents of air or gases capable of evolving sufficient oxygen to keep up the combustion of the carbon contained in the iron till the conversion is accomplished. In March, May, August, and November 1856, and January 1857, further details of methods of introducing the air, assisting the combustion by the use of carbonaceous matter and oxides, and forming ingots, or rolling the molten metal direct, were patented.

Since that time Mr. Bessemer has pursued unremittingly the perfecting of his process, and the results at which he has arrived he communicated in May 1859 to the Institute of Civil Engineers. The primary source of difficulty to be overcome was the removal of the sulphur and phosphorus, abundantly present in ordinary cast-iron, and which the high temperature and copious supply of air in the Bessemer process did not seem to affect. Steam, hydrogen, and silicates of iron and manganese were tried, and with partial success. But the employment of crude iron, free from these noxious elements, appeared the most certain escape from the difficulty, and with

Indian and Nova Scotian iron the process became successful Cast-steel works were erected at Sheffield, and in these the system has since been in operation.

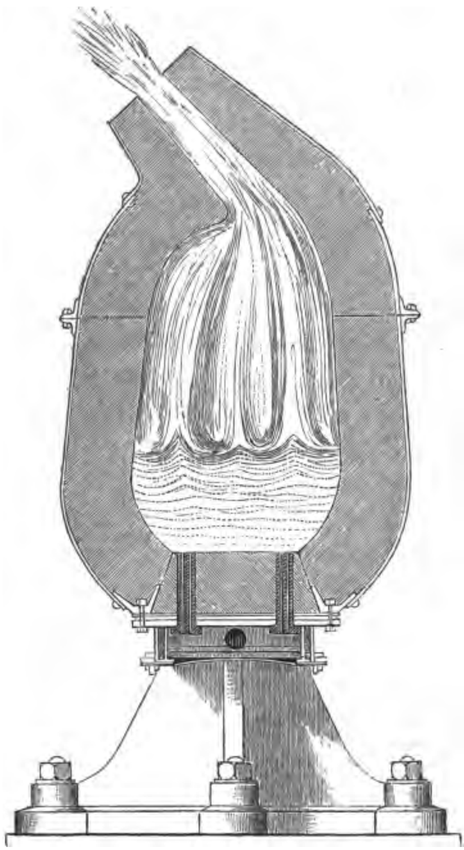


Fig. 51.

For the production of malleable iron, however, this fine description of cast metal was, from its cost, inapplicable, and the iron smelted from specular, hæmatite, and spathose ores, was looked to, to supply the requisite material. Iron was obtained from Cleator, Weardale, and the Forest of Dean, fit for the

purpose, and with the converting vessel, shown in the annexed cut, malleable iron has been produced. Mr. Bessemer thus describes the method of operation: "The vessel is mounted on axes near its centre of gravity. It is constructed of boiler-plates, and lined with fire-brick, road-drift, or 'ganister,' which resists the heat better than any other material yet tried, and has also the advantage of cheapness. The vessel having been heated is brought into a horizontal position, so that it may receive its charge of molten metal without either of the tuyeres being beneath the surface. No action can therefore take place until the vessel is made to assume the vertical position (Fig. 51). The process is thus in an instant brought into full activity, and small, though powerful, jets of air spring upward through the fluid mass. The air, expanding in volume, divides itself into globules, or bursts violently upwards, carrying with it some hundred weight of fluid metal, which again falls into the boiling mass below. Every part of the apparatus trembles under the violent agitation thus produced. A roaring flame rushes from the mouth of the vessel; and, as the process advances, it changes its violet colour to orange; and finally to a voluminous pure white flame. The sparks, which at first were large, change to small hissing points, and these gradually give way to soft floating specks of bluish light, as the state of malleable iron is approached. There is no eruption of cinder, as in the early experiments, although it is formed during the process. The improved shape of the converter causes it to be retained; and it not only acts beneficially on the metal, but it helps to confine the heat, which during the process has rapidly risen from the comparatively low temperature of melted pig-iron to one vastly greater than the highest known welding heats, by which malleable iron becomes only sufficiently soft to be shaped by the blows of a hammer. But here it becomes perfectly fluid, and even rises so much above the melting point as to admit of its being poured from the converter into

a founder's ladle, and thence to be transferred into several successive moulds.

"The oxygen of the air appears in this process first to oxidise the silicium, producing silicic acid, and next to seize the carbon, which is eliminated, while the silicic acid, uniting with the oxide of iron, obtained by the combustion of a small quantity of metallic iron, thus produces a fluid silicate of the oxide of iron, or 'cinder,' which is retained in the vessel, and assists in the purification of the metal. The increase of temperature which the metal undergoes, and which seems so disproportionate to the quantity of carbon and iron consumed, is doubtless owing to the favourable circumstances under which combustion takes place. There is no intercepting material to absorb the heat generated, and to prevent its being taken up by the metal; for heat is evolved at thousands of points distributed throughout the fluid, and when the metal boils, the whole mass rises far above its natural level, forming a sort of spongy froth, with an intensely vivid combustion going on in every one of its numberless everchanging cavities."*

We have been the more particular in giving this extract from Mr. Bessemer's papers from the fact that his process of decarbonisation and boiling, although not exercised to the extent of becoming general, is nevertheless attended with results highly satisfactory as regards the purity and homogeneous state of the metal produced. The greatly increased temperature, rapid combustion, and violent ebullition, and the changes of colour from violet to orange and thence to white, are indications of the different stages of the process, which enable the operator to judge with great certainty when it is time to stop, either in the production of steel of different qualities or malleable iron.

Now, in the usual process of puddling in the reverberatory

* Minutes of Proceedings of the Institute of Civil Engineers, vol. xviii. p. 535.

furnace, these indications are not present to the same extent, as the puddler, when producing either iron or steel, has not only to judge from the colour and the tenacious state of the mass as he gathers it into the balls, but he must close his damper at the exact moment of time, in order to produce the quality of metal, whether steel or iron, that he may require. This is the most difficult part of the process, as the workman has not only to watch his furnace intensely, but the laborious operation of stirring and balling the molten mass is so great as to render him unfit for the double duty of violent muscular action and the exercising of a sound judgment in the appearance of the furnace. To the toil and labour of this exhausting process we may therefore trace the great uncertainty as respects the quality of the so-called homogeneous mass, which is sometimes steel, sometimes iron, or between the two, as it pleases the puddler and his assistant.

Now, the Bessemer process, if it can be safely and profitably carried out, will in a great measure remedy these defects, and give greatly increased confidence in the uniformity, strength, and other properties of the metal produced.

For the production of large plates, Mr. Bessemer has tried one especially interesting experiment, and that is to produce them direct from the fluid metal, without any preliminary solidification. He has rolled a plate of considerable dimensions by pouring the fluid metal into the space between two rolls cooled by water, the metal chilling in a plate as the rolls revolve. If this method could be carried out successfully, we might hope for much larger and more homogeneous plates than is possible with the present system of puddle-balls. We might in fact calculate on a continuous web of iron from the rolls, on the same principle as that produced by the paper-machine, provided the converting or leading furnaces are sufficiently large and numerous to keep up the supply.

The results of experiments on the tensile strength of the

iron and steel produced by this process will be found in Chapter X. They show a very high tenacity.

Wrought iron, as ordinarily made, is found to possess about one-half of the power of cohesion which it has when manufactured in a fluid state, and is allowed to retain a minute quantity of carbon; indeed, iron, under the various forms in which it is met with in commerce, presents an anomaly not to be found in any other of the staple manufactures of this country.

When in the state of cast-iron, the metal contains 4 per cent of carbon, has a tensile strength of 18,000 lbs. per square inch, and is worth £3 per ton. Deprive it of this 4 per cent of carbon, and it becomes malleable iron; it has then a tensile strength of 56,000 lbs. per square inch, and is raised in value from £3 to £8 per ton. But if we leave in it 1 per cent of the carbon it originally contained, it will have a tensile strength of at least 130,000 lbs., and its selling price will have risen from £8 to £50 per ton. Such facts may well suggest the question: Cannot iron be purified, and this 1 per cent of carbon be left in it, without raising its cost to £50 per ton?—Cannot we have the great cohesive strength, the hardness and the homogeneous character of iron fully developed, without that commercial barrier which the old system of making cast-steel has ever placed in the way of its employment for all constructive purposes.

Until very recently, cast-steel has been considered to be a hard and brittle material, and has been employed almost exclusively for cutting tools—its hardness, and the difficulty of working it, rendering it unfit to take the place of iron for general purposes. Well carbonised cast-steel, made by the Bessemer process, has been found to bear a tensile strain of 160,000 lbs. per square inch; while pure decarbonised iron, made by the same process, will only bear on an average 72,000 lbs.

Within these limits, however, there is an ample margin for the manufacture of several distinct qualities of malleable metal, each especially suited to peculiar uses. Thus, steel containing $1\frac{1}{4}$ per cent of carbon, and capable of bearing a tensile strain of 150,000 lbs., may be employed for the upper web of a plate or box girder to great advantage, where it would bear safely an enormous compressive force, but it would be a very improper material to employ in the construction of a steam-boiler.

The light cast-steel girders, of 70 feet span, erected last year on the Thames by the Corporation of the City of London, were made of a mild, tough steel, bearing a tensile strain of 45 tons per square inch, and are of half the scantling of the wrought-iron girders used in the same structure. In many cases it will, however, be perfectly safe to employ a somewhat harder metal than these girders were made of. For instance, some large pump-rods recently made, in lengths of 30 feet each, were required to stand a proof of 120,000 lbs. per square inch. It has, however, been found that iron containing from $\frac{1}{4}$ to $\frac{1}{2}$ per cent of carbon, and capable of bearing from 90,000 to 100,000 lbs. per square inch, is most suitable for general purposes, but it is especially so for steam-boilers, as it will bear punching and flanging like a sheet of copper.* The engraving Fig. 52, carefully traced from a photograph by Mr. Charles Wright, shows several pieces of the Bessemer steel, of the tough quality last named, all of which have been bent or twisted cold. Among them are two pieces of a cast-steel rail, one formed into a spiral, which partly untwisted itself when

* In one establishment near Manchester, six of these steel boilers are in use, under a constant working pressure of 100 lbs. per square inch. Their dimensions are 30 feet in length by 6 feet 6 inches in diameter, the plates being 5-16ths of an inch in thickness. Care must, however, be taken in boilers of this description that the plates are of uniform quality, as a single defective plate would reduce the resisting power of the boiler to the strength of that plate. This requires to be guarded against in every structure exposed to severe strains.

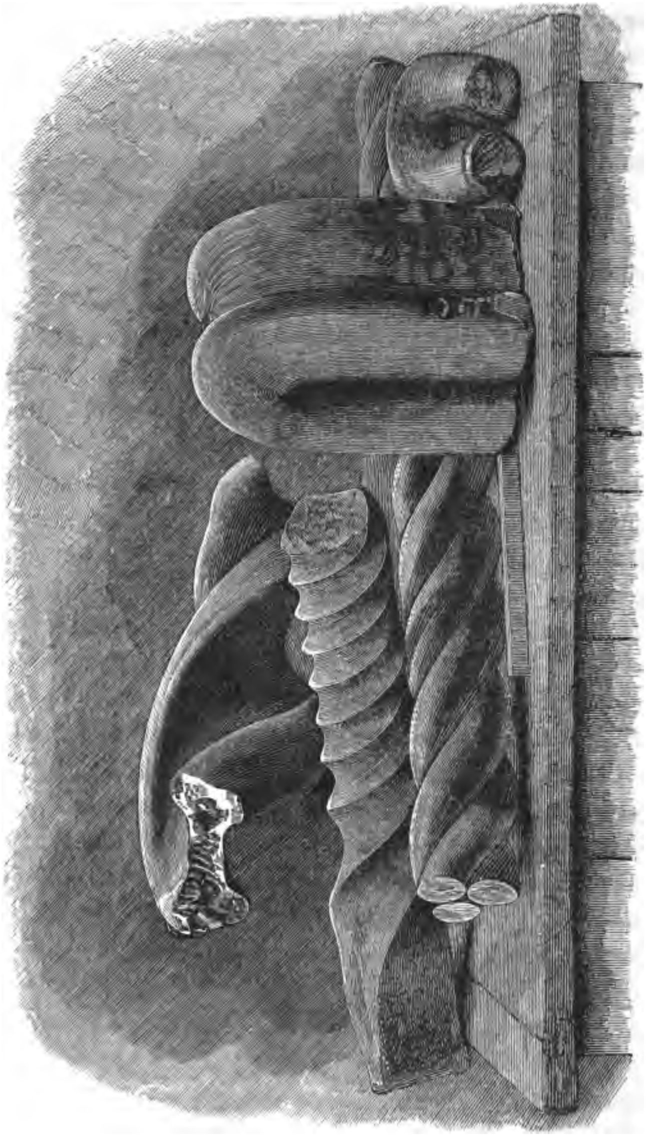


Fig. 52.

released from the machine, and the other folded up by several blows from a $2\frac{1}{2}$ ton steam-hammer. There is also shown a 3-inch square steel bar, which affords a good example of the power of this metal to resist fracture by a torsional strain. Its angles, originally 3 inches asunder, are seen to approach within $1\frac{1}{8}$ of each other, the original flat sides of the bar being formed into a deeply indented groove; and in the space of 12 inches from the fractured end, the angles, measured on their present extended line, are equal to 22 inches in length. These examples of extreme toughness and power to resist fracture until entirely altered in form, will, it is hoped, tend to dispel the very popular error, that cast-steel "snaps like glass," and cannot be safely employed as a substitute for wrought iron.

To the details of the process by which these results have been obtained, at a cost which can compete successfully with common iron, already given, Mr. Bessemer has furnished the following additional particulars. Fig. 53 represents an external view of the converting vessel A and its accessories. The converting vessel has already been described and figured at page 152. This vessel is supported on axes, which project on each side of it, a little above its centre of gravity, and these rest on the standards B, which are firmly secured to the foundation. On one of the axes a spur wheel, C, is fixed, which receives motion from the pinion and handle D, so that at any time a semi-rotatory motion of the vessel may be effected by simply turning this handle in the required direction. In front of the vessel is fixed a hydraulic crane E, having an arm G, to which the casting-ladle H is attached. A semicircular casting-pit J is sunk in the floor, and has placed in it any convenient number of ingot-moulds K, arranged side by side, all of them being equidistant from the centre of the crane. The casting-ladle is raised and lowered down as near as convenient to the mouth of the moulds. This crane and ladle are shown in section in Fig. 54. The inside of the ladle

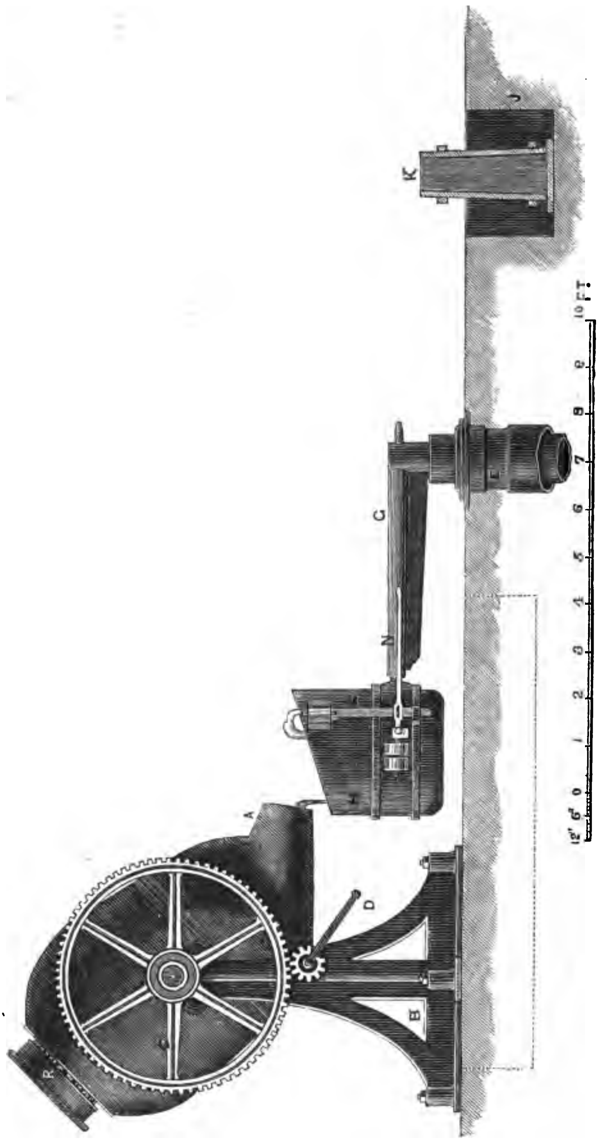


Fig. 53.

is defended by a coating of loam, and at the bottom of it an opening is made, to which is fitted a small tubular piece of baked fire-clay. Another piece of fire-clay, of a conical form, is fastened on the lower end of the rod L, forming a sort of cone-valve. The rod rises above the top of the ladle, and descends on the outside of it. The outer limb of this fork-shaped piece passes through guides attached to the ladle, while that part of it which occupies the interior of the ladle is defended from the action of the fluid metal by a coating of loam. By means

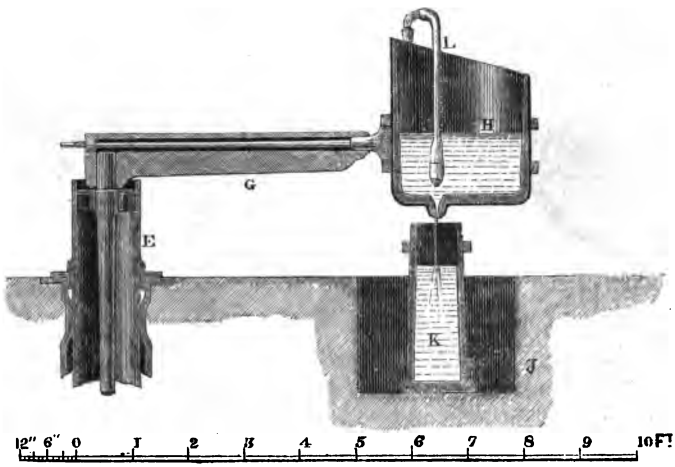


Fig. 54.

of the handle N, this forked rod is moved up and down, and thus opens or closes the orifice in the bottom of the ladle when desired, and thereby regulates the admission of the metal into the several moulds, and entirely stops the stream while the crane is moved on its axis from one mould to another. This mode of filling the moulds is rendered necessary, on account of the extreme difficulty which is found in pouring the fluid steel over a lip formed on the top edge of the ladle, without allowing some of the fluid slag to go over with the metal and become intermixed with it. The rapidity with which the solidification

of malleable iron takes place in a cold metal mould would prevent any slag that might be taken down with the falling stream from rising again to the surface. It is also essential that the metal should descend in a vertical stream down the centre of the mould; for if the stream is allowed to flow in contact with the cast-iron mould, the latter is immediately melted at that part, and becomes firmly united to the ingot.

The blast of air is conveyed into the converting vessel through one of the trunnions, which is made hollow for that purpose, and passes by a pipe into the tuyere-box R, which is so arranged as to be easily detached. Two or more of these tuyere-boxes are provided, so that on the removal of one set of tuyeres, another box and tuyeres may be in readiness to replace it. The tuyeres are seven in number, each one having five separate holes through it, of $\frac{1}{4}$ of an inch in diameter. These holes allow the air to pass vertically upwards into the mass of fluid metal in 35 separate jets.

When the apparatus cannot be supplied with fluid metal direct from the blast-furnace, it has been found preferable to melt the pig-iron in a reverberatory furnace, from which the metal may be conveyed in a ladle to the converting vessel, which is moved into a nearly horizontal position to receive it, the tuyere end of the vessel being sufficiently raised to keep the orifices of the tuyeres above the level of the metal. When about 25 cwts. of crude iron have been run in, the blast is turned on, and the vessel is rapidly moved into the position shown in Fig. 51, when the process instantly commences, the jets of air rushing upwards, expanding in volume, and dividing into an infinite number of globules, which become dispersed throughout the fluid mass. The silicium is first attacked, neither the iron nor carbon being operated upon to any extent while any silicium remains. When the crude iron contains about $1\frac{1}{2}$ per cent of silicium, it requires about twelve minutes' blowing to remove it, during which time only a few sparks make their

appearance; but as soon as the silicium is nearly all eliminated, the carbon and iron are more and more acted upon. At about this period, two minutes suffice to entirely change the outward indications of the process, for in that short space of time the bright sparks previously seen issuing from the vessel have almost wholly disappeared, and a voluminous flame rushes out of the mouth of the vessel, gradually passing from orange colour to a brilliant white. The light is so intense as to project shadows of every object on the wall of the building, even at mid-day. In about twenty-five minutes from the commencement of the process, this flame is observed to drop off suddenly, thus indicating the complete decarbonization of the metal. Combustion can therefore no longer go on. The vessel is then immediately turned again into the horizontal position, and a small quantity of carburet of manganese, mixed with carburet of iron and silicium, added, when the vessel is again turned up, and the blast driven through it as before; the manganese almost wholly disappearing in a few seconds, whilst the carbon is retained. The steel may thus be carbonised to any desired extent, entirely depending on the known quantity of carbon thus added to the converted metal, while the carburet of manganese effects precisely the same chemical change as it does in the thousand other steel pots in which it is daily employed in Sheffield—*i.e.*, it confers on it the property of welding and working more soundly under the hammer. Mr. Heath first discovered this important fact while residing in India, and in the year 1839 he patented the discovery in England. So well did he understand the chemical changes brought about by the employment of this alloy in steel, without reference to the mode by which the steel was manufactured, that he claimed in his patent "the employment of carburet of manganese in any process whereby iron is converted into cast-steel." No sooner is the mixture of the metals effected than the casting-ladle is brought under the mouth of

the vessel, which is then turned down, as shown in Fig. 53, and the fluid steel poured into the ladle; the ram is then raised by simply turning a handle, and the crane-arm is swung round so as to bring the orifice of the ladle over one of the moulds; the handle N is then depressed, which raises the fire-clay valve, and allows the fluid steel to flow in a clear round stream into the iron moulds beneath; all slags or dry oxides float on the surface of the fluid in the ladle, and cannot possibly enter the mould. When one mould is filled, the cone-valve is shut down and the ladle is moved over the next mould, and so on until all the steel is formed into ingots, the process occupying thirty minutes from the pouring in of the crude iron to the formation of the metal into cast-steel blooms or ingots.

The metal silicium plays a most important part in this process; and however injurious it may be found when present in comparatively large quantities, it is of the utmost service when employed in minute doses. Whenever decarbonised fluid iron is deprived of every atom of silicium, as in the process just described, or when blister-steel free of silicium is melted in crucibles, it is found to disengage gas rapidly in the act of cooling (in the same way that silver does), and thereby produces unsound castings, the steel in some cases boiling in the cold cast-iron mould so furiously as to run over the top, and more than half empty the mould. When the metal is in this unmanageable state, it has been found that 1 lb. of silicium put into 2000 lbs. of steel entirely stops the boiling action, and causes the metal to lie as quietly in the mould as common cast-iron would do. Now, the metal silicium is most difficult to obtain in such quantities as are required for commercial purposes, but, like manganese, may be reduced most readily when intimately combined with oxide of iron. Hence the metal put in at the end of the process is an alloy of manganese, silicium, and iron, obtained by the simultaneous reduction of their oxides previously mixed in the requisite proportions.

It is curious how, by the merest accident, and entirely without their knowledge of the fact, the steelmakers on the old plan have for the last forty or fifty years taken the benefit of this alloy. In making the 5000 crucibles which daily are put into the steel furnaces of Sheffield, it has been found most convenient to form them with a small round hole in the bottom. These crucibles are placed in the furnace upon a flat lump of fire-clay, and a handful of sand is thrown into them for the purpose of stopping up this hole and preventing the escape of the steel. The intense heat of the smelting process, aided by the carbon present in the steel, and by the small quantity of charcoal usually put into the crucibles with it suffices to reduce a small portion of the sand or silicic acid into the metallic state; the silicium thus formed alloying the steel, gives that quietness and freedom from boiling known in the trade as "dead melted." The analysis of cast-steel of the highest qualities invariably shows this alloy of silicium.

At present there are two distinct modes of working the Bessemer process: that just described is the system preferred in England; but in India and Sweden, where the process is rapidly extending, the fixed vessel has been adhered to, and the various qualities of steel and malleable iron at the works of Mr. Göranson of Geffle are entirely regulated by the quantity of blast and the time of blowing; no manganese is used at any stage of the process, nor is any metal added to regulate the temper of the steel. Over 700 tons of steel so produced have found their way into the English market within the last seven months, the whole of which was made in precisely the manner described by Mr. Bessemer in his paper read at Cheltenham in 1856, and quoted at the commencement of this chapter.

In the conversion of crude iron into steel by a blast of air, a great waste of metal may be made, if the quantity and mode of applying the blast is not directed by a person having a

practical knowledge of the process; but with this knowledge (easily acquired), the loss of metal is extremely small. Mr. Göranson, who employs the fluid crude iron direct from the blast-furnace, took the trouble to weigh accurately all the fluid iron employed for this purpose at his works during a whole week, and in his report of the results obtained, he states the actual loss in weight to be 8·72 per cent—that is, the cast ingots, together with the scrap or steel accidentally spilled, was within 8·72 per cent of the weight of cast-iron tapped from the blast-furnace. At the Sheffield works the iron is melted in a reverberatory furnace, which causes a loss of 5 or 6 per cent in the first instance; and coke-made pig-iron being less pure than that employed by Mr. Göranson, a further loss of about 10 per cent takes place in the converting vessel, making a total loss of 15 or 16 per cent of the pig-iron employed. The loss has occasionally been as low as 13 per cent and as high as 20, but it is believed that it will be further reduced when converting five tons of crude metal at a single charge. Not only is the loss in the converting process small; but in the after process of hammering and rolling, the loss from oxidation is much less than that which takes place in making wrought-iron in the usual way—*firstly*, because the temperature of the blooms is much less; *secondly*, because it is only worked once without piling; and, *thirdly*, because the solid ingot presents very much less surface to oxidation than a pile of small bars. Hence it follows that a ton of pig-iron may be converted by the new process into bars or plates of cast-steel in much less time, with less fuel, with less manual labour, with less engine-power, and with a less loss of metal, than the same ton of pig-iron can be made into common wrought-iron by the ordinary process, to say nothing of the increased commercial value of the product.

An important feature of the new process is, that it affords great facility for the production of large masses of tough malle-

able metal, without increasing the cost in the same ratio as in the old process, where every large mass is built up of small pieces more or less perfectly united, and more or less injured in quality, by being reduced to a soft state approaching fusion, in order to favour the adhesion of each successive piece as it is added to the mass.

When a large forging of the Bessemer steel is required, the fluid metal is poured into a massive iron ingot mould equal in weight to the fluid metal, where it passes in a few minutes into a solid state. The rapidity with which the iron mould absorbs the heat is shown in eight or ten minutes after pouring in the fluid steel, by the mould becoming red-hot, although sometimes weighing more than a ton. The result of this rapid solidification is the formation of small crystals not easily detached from each other, as is the case with large and well-defined crystals produced by slow solidification.

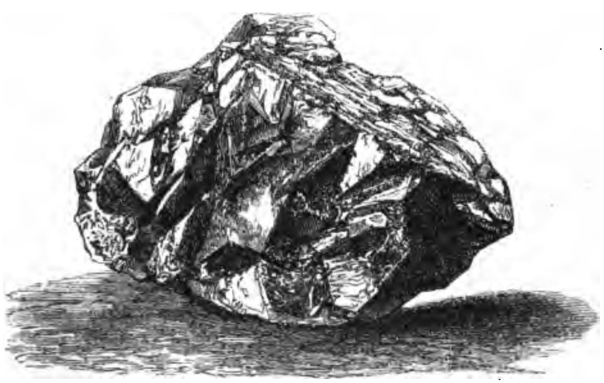


Fig. 55.

In all cases, the employment of metal containing phosphorus should be avoided, as that substance assists in the development of crystals in a most extraordinary manner, and thereby causes the metal to be cold-short. The effect of this substance on some other metals is most remarkable: if one

ounce of phosphorus be put into one cwt. of melted tin, it entirely alters the whole character and properties of the metal; for on cooling, the mass crystallises in large and distinct crystals, having so feeble a cohesion as to allow of their separation by a very light blow. Fig. 55 is copied from one of Mr. Wright's photographs of a fragment of phosphorised tin, and shows how large and perfectly the crystals are developed in a piece of only 2lbs. in weight.

As an illustration of the mode of treating large masses, an instance may be given in which the crude pig-iron was tapped from the reverberatory furnace at 10 A.M., and by 10.30 was converted into mild cast-steel, and formed into an ingot of 16 inches square by 3 feet 6 inches long; at 10.50 it was removed from the mould and put into the heating furnace, in order to restore a little of the heat taken from its exterior by the mould, and thus render the whole mass nearly uniform in temperature, the central part still being a little higher in temperature, so as to be readily acted upon by the hammer. During the afternoon this ingot was formed by hammering into a truncated cone 7 feet 10 inches long, and 10 inches diameter at one end, and 8 inches at the other, and was the first gun-block made by the Bessemer process in steel. In December last it was finished at Liege, and proved under the direction of the Belgian Minister of War; it was bored for a 12-lb. shot, the interior being $4\frac{3}{3}\frac{2}{2}$ inches diameter, the exterior being finished at $9\frac{1}{2}$ inches diameter at the breech end, and $7\frac{1}{2}$ inches at the muzzle, weighing 9 cwt. and 23 lbs.; whereas an ordinary cast-iron gun of the same calibre would measure 16·22 inches diameter at the breech, and 10·39 at the muzzle, weighing 34 cwt. The steel gun (if such a thin tube may so be called) was ordered to be proved *à l'outrance*, with increasing charges of powder and shots until it should give way. The charge for commencing the proof was 4 lbs. $7\frac{3}{4}$ oz. of powder and two 12-lb. shots. The charges of powder and the number

of shots were increased up to the twenty-second round, when the gun gave way under a charge of 6 lbs. 11½ oz. of powder and eight 12-lb. shots. The gun did not burst longitudinally, but separated in two pieces, about four feet of the muzzle end being blown off. This will afford some idea of the great tenacity of metal, even when of large section, and not much worked under the hammer. Nor must this be considered as a maximum result; since the precise quality of metal best suited to this purpose can only be determined by numerous trials, it is highly improbable that the best temper was arrived at on the first attempt.

While cast-steel made by the direct conversion of pig-iron is quietly working its way into the great engineering establishments of this country, and some of our most wealthy and enterprising iron and steel manufacturers are preparing to exchange the old for the new system of making steel, the daily working of the process only affords fresh proof of the desirability of a still further improvement in the apparatus employed. The change of tuyeres in the present vessel causes a delay of four or five hours, and allows the vessel to get cold in the interval, and thus impedes that rapid and continuous working which is so highly desirable. The loss of time occasioned by the present mode of setting the tuyeres has led to an important improvement in the construction of the apparatus, which will enable the workmen to convert a charge of metal every hour, night and day without interruption, and thus render the heating of the vessel from time to time with fuel quite unnecessary, and enabling a small vessel to turn out 200 tons of steel per week.

In this improved converting vessel the globular form has been chosen, because it is easy of construction, and well suited to sustain its great weight from two points of support; the lining of the interior is also more stable than with any other form, and presents less surface for radiation of heat. The

apparatus is shown in section in Fig. 56, and in elevation in Fig. 57. The casting pit extends beneath the vessel A, which is placed so low down that a charge of crude iron may be run into it by a gutter on the level of the floor; like the former vessel it is supported on trunnions, and carries on one of them a pulley-wheel B, around which passes a wire-rope attached to a hydraulic lift or ram; a counterweight is suspended from the opposite side of the drum. The whole of this apparatus being below ground is operated upon in a similar manner to the casting crane before described, and which is also used with the new vessel.

In this modification of the apparatus the tuyere box is entirely dispensed with, the air not being admitted through separate tuyeres let into the bottom of the vessel, but the blast is brought downwards by a single tuyere, D, from the upper part of the vessel, so that the tuyere may be removed from the vessel and a new one put into its place without disturbing the lining of the vessel. It is raised or lowered when required by a small hydraulic crane E, having a long tubular arm extending to the upper end of the tuyere. The blast-pipe G rises vertically from the floor level, and is parallel with the plunger of the hydraulic crane; an elbow-pipe H, having a telescopic joint, establishes a communication at all times between the blast-pipe and the tuyere, notwithstanding the motion of the crane, in any direction; thus the whole movements of the converting and casting apparatus are effected steadily, and without effort, by any workman in charge of the handles of the hydraulic apparatus. After a charge of metal has been converted, the tuyere is lifted out, and the vessel turned round so as to pour it into the casting ladle; the vessel is then turned up, and the tuyere again inserted, or a new one is put in if the old one is too much worn. The tuyere is composed of circular bricks having a central hole, through which a stout iron rod passes, and by means of which the tuyere is

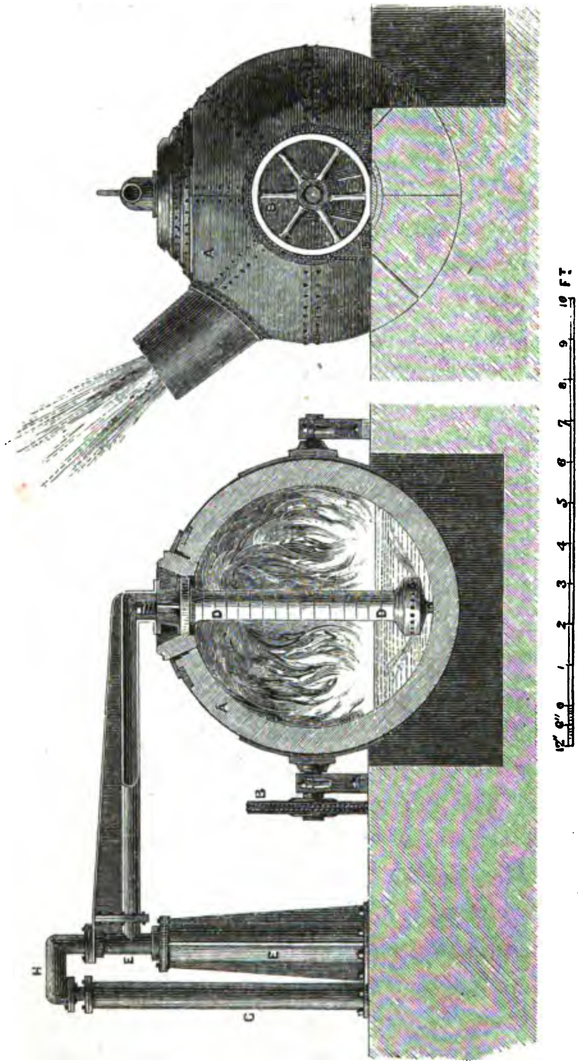


Fig. 57.

Fig. 56.

firmly held together; the passages for the air surround the central rod, and the current of air passing down them, prevents the rod from being made too hot. The vessel is 7 feet in external diameter, and capable of converting from 2 to $2\frac{1}{2}$ tons

of steel at each charge, the process occupying about 25 minutes.

In order to prevent a stoppage of the operations in the converting-house by any accident occurring to the converting apparatus, it will be found preferable to mount two vessels at each casting-pit. This plan has also the advantage of allowing the two vessels to be used simultaneously when any very large ingot or casting is required; and it must be borne in mind that this facility of producing steel or malleable iron castings in loam moulds is another most important feature of the new process, arising out of the treatment of malleable iron in a fluid state. Wherever lightness and great strength are required in iron castings, this material should not be overlooked by the engineer. The framing of marine engines, screw propellers, the cylinders of hydraulic presses, and a hundred other uses, will present themselves, when it is known that castings can be made of this malleable metal, and portions of these castings may be forged and drawn out if required, and will give to such parts a great additional strength. For example, the mouthpieces for the scoops of a dredging machine were, for sake of convenience, cast as flat plates of the peculiar shape required, and were bent afterward into the proper form to fit the scoop. The unhammered malleable iron has a tensile strength of 41,000 lbs., and steel in the same condition 63,000 lbs., this being the mean of eight different trials made at the Woolwich Arsenal. Taking the weekly produce of a pair of 7-feet converting vessels to be only 200 tons of cast-steel, their powers of production will present a curious contrast to the immense series of buildings and furnaces required to produce this quantity of cast-steel by the old process, for which purpose most extensive works would be required; for, even after the pig-iron has been made into malleable iron bars, and these bars have been kept at a white heat for eight or ten days, and have been converted into blister-steel, the mere melting

of this steel, and casting it into ingots, would require no less than 4750 crucibles, with their lids and stands, 200 workmen, 60 boys, 700 tons of hard oven coke, and 760 separate melting furnaces, costing for their erection £31,500.

We are informed that in Sweden several companies are already using the process, the purity of their iron offering peculiar advantages in its application; and in France, Belgium, and Sardinia, it is already being carried into effect.

Since these remarks were first written, great improvements have been effected by Mr. Bessemer in the several details of his direct steel process. The obvious advantages of working out the invention on the large scale originally contemplated by him at the time when he read his first paper at Cheltenham, had become every day more and more apparent. In working vessels of so much larger dimensions, it becomes necessary that some means of moving them by power should be adopted, instead of employing manual labour for that purpose, as heretofore practised. But a perfect control of the movement of the converting vessel on its axis presented some difficulty. A vessel of the requisite size for converting 6 tons of crude iron at a charge will weigh, when in use, about 23 tons, and is 11 feet in height; the main body of it is of cylindrical form; and as it approaches a position in which the cylinder becomes horizontal, the 6 tons of fluid iron commences running to the opposite end of it; thus the power required to turn the vessel on its axis undergoes a constant change, and at a certain point the load is reversed, and the vessel tends to run itself entirely over, and throw out its contents upon the floor. When in the act of pouring fluid steel from the vessel, the speed at which it must be moved so as to pour a uniform stream is also subject to great variation; and as it sometimes tends to boil over in the ladle, it is essential that the operator should be able in-

stantly to vary the speed, or entirely to stop the movement of the vessel for a few seconds, or even to reverse the motion if necessary. The great heat radiated from such a large quantity of incandescent metal, and the showers of sparks and slags thrown out during the process, render the use of leather belts, cone drums, and all the other ordinary appliances in use for changing and reversing speeds, entirely inapplicable in this particular case.

It was to obviate these difficulties, and to give to the operator perfect control over the movements of the vessel from a distant point, that Mr. Bessemer introduced the system of hydraulic apparatus, now in general use, and which consists simply of a cast-iron cylinder of one foot in diameter, to which a piston is fitted with double cup-leathers; the piston-rod is made of steel, and the outer end of it is formed into a rack, gearing into a spur-wheel, the axis of which is supported in stout plummer-blocks, attached to the bed-plate on which the water-cylinder is fixed; the axis of the spur-wheel is connected by a clutch to the axis of the vessel, so that the motion of the piston from one end to the other of the cylinder will cause a semi-rotation of the vessel on its axis; a pipe proceeds below ground from each end of the water-cylinder to the valve-stand, where the operator is stationed; here a handle is placed which turns a two-way cock, through which water under pressure is conveyed to one side of the piston, while the other side of it is open for escape. The workman, by reversing his handle, will communicate the pressure to the opposite side of the piston, and instantly reverse the motion of the vessel; he can also stop the handle midway between these extremes, and cut off all ingress or egress from the cylinder, and thus render the vessel immovable in any desired position, the slowness or quickness of the motion being also under perfect control by simply opening or shutting the two-way cock more or less completely.

A converting vessel of 23 tons in weight is thus put under the perfect control of a boy standing on an elevated platform 50 feet from the vessel, from which position he commands a view of all that is going on, although far removed from the heat and the showers of sparks and slags that are sometimes emitted from the vessel in all directions. The water pressure employed for this purpose generally does not exceed 400 lbs. per square inch, and is obtained from a 10-horse donkey-engine working a set of four or six plunger-pumps, which deliver their water back again to the supply-cistern under a loaded valve, when not working any of the hydraulic apparatus; but as the same set of pumps are employed to work the casting-crane, the two ingot-cranes, and the steam-hammer cranes, they are all kept in full activity.

The necessity for changing the worn-out tuyeres and the relining of the converting vessel was a source of much loss of time when one vessel only was used, and prevented a continuous working of the process night and day. To avoid this inconvenience, Mr. Bessemer introduced the plan, now generally adopted, of working two vessels in one casting-pit, where one vessel is used while the other is under repair. By this arrangement a great economy of time is effected, while the continuous working of the apparatus, from week's end to week's end, has been found to give most economical and beneficial results.

The general arrangement of the apparatus will be better understood by referring to Fig. 58, which is a view of the interior of the converting house, a plan of which is also shown in Fig. 59. It will be seen that two vessels, A A, are employed; they are placed in such a position as to throw the sparks and slags away from each other, and into the lower part of the chimneys, BB, which have hoods at B* to conduct the flame into them. The casting-pit is semicircular in front, and central with it is placed the casting-crane C,

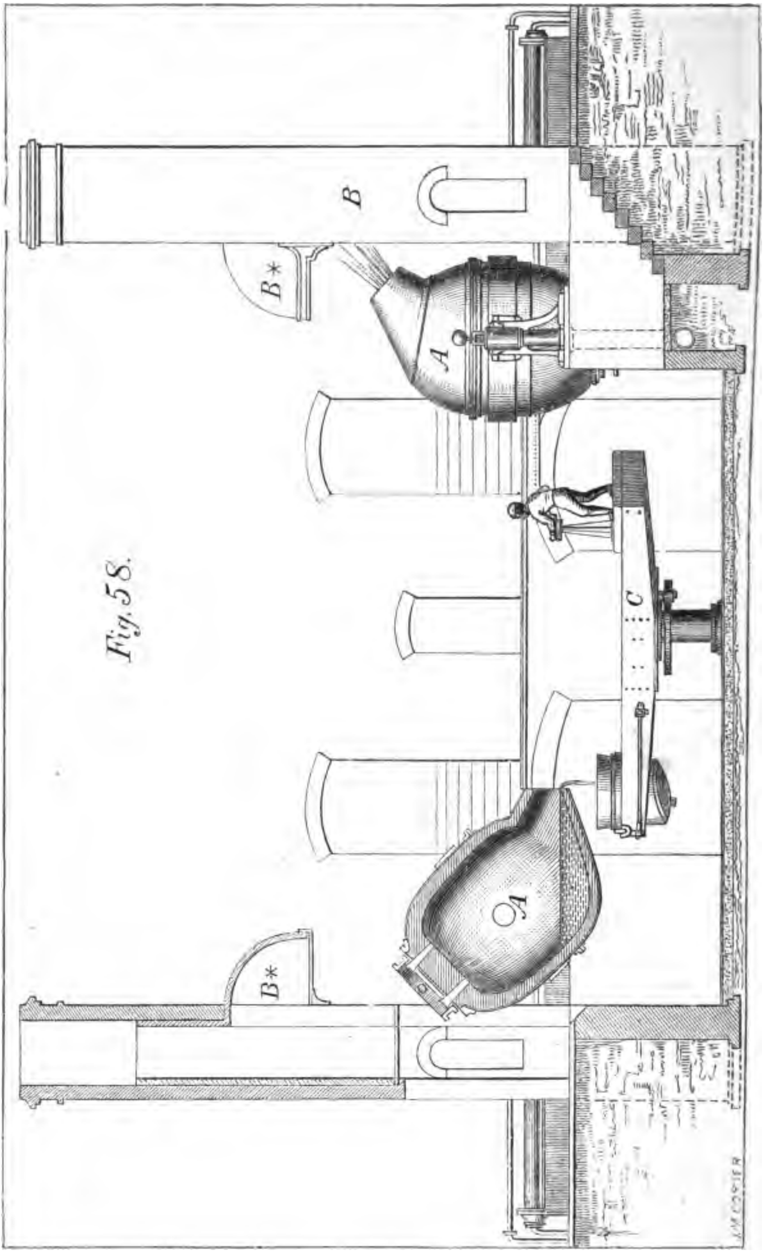


Fig. 58.

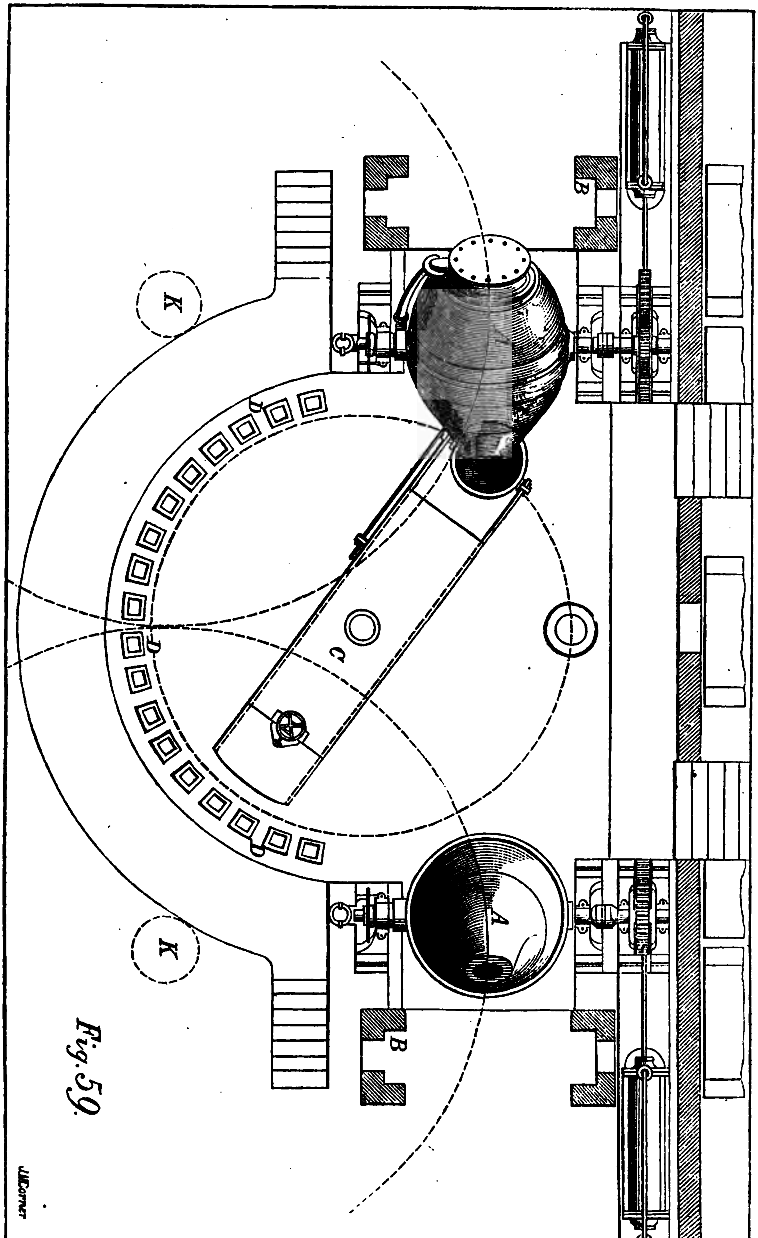


Fig. 59.

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which supports the ladle into which the fluid steel is received, and from which it is delivered through a cone-valve into the moulds D D. One of the vessels is shown in section in the act of pouring out the steel into the ladle, while in the other the process of conversion is going on. When necessary, both vessels may be worked at the same time, and their contents poured into one large ladle, so that an ingot of 10 tons may be made by what is usually styled a 5-ton apparatus. This double working of the apparatus has been frequently had recourse to with most perfect success. It will be observed that the casting-crane C is brought so far forward, from a line passing through the centre of the converting vessels, as to allow one vessel to be moved round if necessary, while the ladle is in front of the other vessel. This position of the crane enables the casting-pit to be made larger, and gives more space for the moulds. In the act of pouring the steel from the converter into the casting-ladle, the crane is steadily lowered, and its head moved round to accommodate the curved path in which the spout of the converting vessel moves. This lowering of the crane is effected by the boy on the valve-stand, which is situated at a distance of about 20 feet from the casting-pit, and in a line with the centre of the casting-crane. On this stand, the cocks for moving each of the vessels are placed; here also are the handles of two large balanced air-valves by which the blast is regulated. In the early stages of the manufacture much loss of time was occasioned in moving the moulds, by an ordinary crane, into and out of the casting-pit. Some of the moulds weigh upwards of 5 tons, and powerful cranes were therefore necessary for moving such large masses; but when it was required to make a 4-ton charge into ingots of only 5 cwt. each, the slow action of a heavy crane was most inconvenient; the workmen had first to lift up the block which forms the bottom of each mould, and to lower it down into its proper place in the

casting-pit; this operation had to be repeated as many times as there were moulds required, and which, in the case supposed, amounted to sixteen; then the sixteen moulds had, in like manner, to be moved from the stage where they were kept when not in use, and had to be conveyed, one at a time, to the pit, and placed upon their respective stands; and when the ingots were cast, the removal of the sixteen red-hot moulds had to be effected, and then the red-hot ingots had to be lifted from the pit, and the bottoms of the moulds had also to be again moved to make way for another set, thus bringing the crane into operation no less than eighty times for a single operation of the converting vessel. This was a source of much loss of time, and was found to retard the whole process. A new crane for this especial purpose was devised by Mr. Bessemer, which can be worked by one man and a boy with a degree of rapidity wholly at variance with the ordinary slow motion of such machines.

This apparatus is shown in elevation at Fig. 60, and in section at Fig. 61. It consists of an upright cylindrical ribbed casting *a*, with a large flange at the lower part, by means of which it is secured on its foundation. The upper part of the cylinder *a* has an hydraulic leather and gland *b*, through which the ram or crane-post *c* can slide freely. This ram is made of two different diameters; the lower part of which, being the smallest, passes out of the cylinder through another gland *d*. The top part of the crane-post or ram is made conical, and supports a hollow conical casting *e*, which is free to revolve on a ball-joint formed on the top of the cone. There are also a pair of anti-friction rollers at *f*, which allow the head of the crane to move round with very little force. On one side of the casting *a*, a wooden beam *g* is fixed, having an iron rail on its upper side, the outer end being supported by light steel tension-bars. A small carriage *h*, with two wheels, runs on the rail, and to it a chain is suspended,

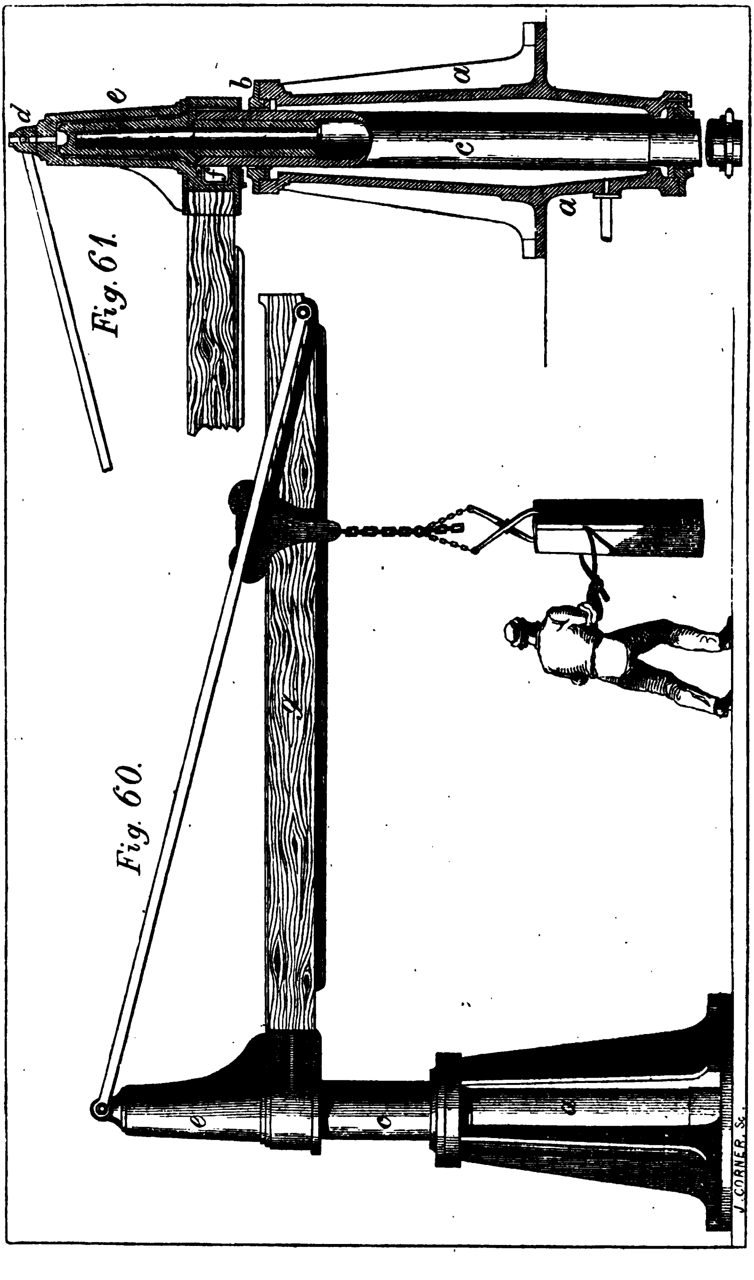


Fig. 61.

Fig. 60.

carrying at its lower end a pair of tongs, which simply close with the weight of the mass within their grip. When this crane is in use, the boy on the valve-stand allows the water occupying the cylinder *a* to escape, by which means the crane is lowered, the tongs are to be opened, and placed over the piece to be moved. The handle of the cock is then reversed, when water under pressure will enter the cylinder *a*, and, acting on the ram or crane-post by reason of its difference in diameter, lifts it quickly up, whether its load be of 1 cwt. or 5 tons. The workman then, with a light pair of tongs, pulls the suspended ingot towards him, which causes the head of the crane to turn round. If he desires to set down the load at or near the extremity of the crane-arm, he pushes it in that direction, or in the opposite one if desired. It is found that if he pushes the suspended weight only a few inches on either side of a vertical line from the point from which it is suspended, that either the carriage *h* will traverse the rail, or the head of the crane will turn on its ball-joint. Thus with perfect ease a single workman will, with one of these cranes, pick up and set down a load of several tons at any point within a circle of 35 feet in diameter with a degree of ease and rapidity that no description can convey an adequate idea of. Two such cranes are erected, one on each side of the casting-pit, as shown at K K, Fig. 59.

This description of crane, having a steel ram and wrought-iron beam, in lieu of the wooden one, is employed at the works of Messrs. Bessemer and Co. for moving the forgings under their largest steam-hammers, the traverse motion in that case being effected by a long hydraulic cylinder of only 3 inches diameter, mounted horizontally on a level with the small traversing carriage to which the piston-rod is directly attached. The chain which supports the forging has a spring swivel let into it, so that not the smallest concussion is transmitted to the head of the crane. The ease and rapidity

with which a boy can move a 6 or 8 ton forging from the furnace, and regulate its height and position under the hammer, with one of these simple machines, renders it a great favourite with the forgemen.

By means of the various mechanical appliances which Mr. Bessemer has engrafted on his original process, the amount of labour, and the exposure of the workmen to heat, when dealing with 5 tons of fluid steel, is found to be far less than has to be encountered in the manipulations of an 80-lb. puddle-ball, or the removal from the furnace of a set of 30-lb. crucibles of cast-steel; but while the exposure of the workman to severe temperatures, and the reduction of manual labour by a series of almost self-acting hydraulic apparatus, has been effected, improvements of equal importance have been made in the converting process, by which the degree of carburation and toughness of the metal are put under the most perfect control of the workman, who, by weight and measure, can insure a thousand consecutive charges of precisely the same quality, or he can vary it by almost imperceptible gradations, from the hardest steel to the softest malleable iron. The importance of such a result will be fully appreciated by all who know how completely the quality of each bar of common iron depends on the judgment and skill of the puddler, and how the degree of hardness or "temper" of all cast steel is simply regulated by the eye of the workman, who decides by the mere examination of the fractured bar of blistered steel what will be the quality of the cast-steel obtained by its fusion.

Mr. Bessemer states, that in his system, as commonly practised, much of the uncertainty that attaches to the old modes of manufacture was got rid of, and that he should probably have been content to have left the process in that condition had not the great success which has attended it, and the rapidity with which the process is being adopted

both by iron and steel manufacturers throughout the country, called forth, from those who feel themselves interested in opposing its progress, the most severe criticisms on the quality of his metal, alleging its great want of uniformity in temper or hardness. Mr. Bessemer says it is true that in this respect perfection was not attained, and that, in common with all iron and steel manufacturers on the old plan, the products of his process were subject to some variations in quality; but the system of weighing which he has introduced, if rigidly carried out, must give results far more accurate than the eye of the most experienced workmen can possibly arrive at. In the process as usually carried on, 6 tons of pig-iron are put into a reverberatory melting-furnace, and 4 cwts. of a carburet of iron, containing about 4 per cent of carbon and 6 per cent of manganese, are melted in a separate chamber, and, so soon as the 6 tons are wholly decarbonized and converted into malleable iron, the molten carburet is poured into it, and there results a given quantity of steel. By increasing or decreasing the quantity of carburet of iron, a harder or milder steel is obtained. This is certainly an approach to a system far more perfect in principle than the mere observation of the workman; but it has been, on investigation, discovered subject to several small sources of error, which may be thus enumerated:—

Firstly, It is found that, however accurately the 6 tons of pig-iron constituting a charge have been weighed, the actual weight of pure iron present is unknown, since it sometimes varies from 93 to 95 per cent of the gross weight, and thus constitutes an error of 2 per cent in the estimated quantity.

Secondly, The loss of weight in the melting-furnace may vary from 5 to 6 per cent.

Thirdly, Either a small portion of the 6-ton charge may be left in the hollows of the furnace, or a small portion of a former charge remaining in the furnace may be thus added to it.

Fourthly, A small portion sometimes remains in the gutter which conveys it to the converting vessel.

Fifthly, The loss of weight, including the carbon, etc., consumed in the converting process, varies from 7 to 9 per cent; the quantity thrown out during the boil is also uncertain, and a small portion of the metal may be left adhering to the roof of the converter, or, as sometimes happens, a small portion left there of a former charge may be remelted during the process, and thus add to the weight of the charge of malleable iron to be carburetted.

These sources of error are known and allowed for in practice, and are found in general to neutralise each other so far as to afford satisfactory commercial results, but they clearly leave much to be desired on the score of critical accuracy. With reference to the carburet of iron to be added to the pure decarbonised metal, Mr. Bessemer has shown how this also is subject to several sources of irregularity. In the first place some pigs will contain 8 per cent, and some only 6 per cent of manganese, while the quantity of carbon will vary from 3½ to 4½ per cent. The quantity of iron put into the melting-furnace may get a small addition from a former charge, or a portion of it may be left there; but the quantity, both of carbon and manganese, lost by oxydation in the melting-furnace, is very uncertain, and may affect the final result more than any other of the sources of error before named. This catalogue of errors seems formidable enough, but on investigation it simply resolves itself into two sources of error—viz., the actual weight of pure malleable iron to be carburetted, and the quantity of carbon and manganese remaining in the metal to be added to it. The remedy which has been devised is as simple as it is effective. In the casting-pit, a flat table weighing-machine is fixed on a level with the floor. The casting-ladle is made to detach itself from the crane by simply lowering the crane until the

ladle rests steadily on the three short legs upon the weighing-machine; the weight of the ladle having been ascertained, it is again raised up by the crane, and the pure malleable iron is then poured from the converter into it; the ladle is again placed on the weighing-machine, and in one minute all the various sources of error before mentioned are annihilated, by actual weight of pure malleable iron to be carburetted having been ascertained to a single pound.

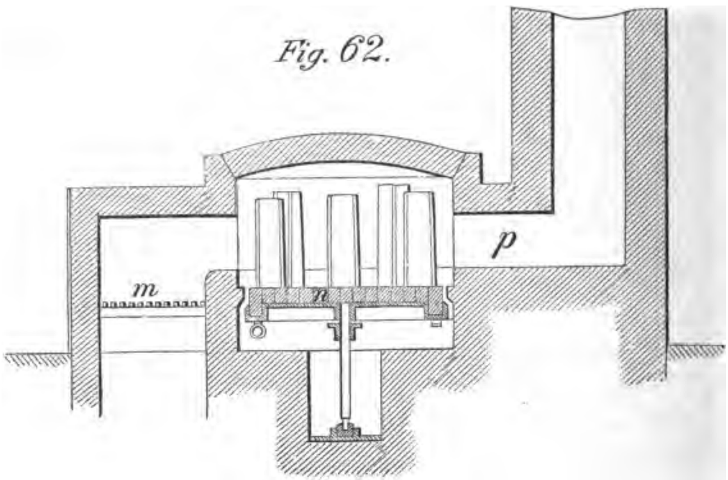
With regard to the carburetting metal, Mr. Bessemer observes as follows:—When the fluid carburet is run from the blast-furnace in which it is obtained from the ore, it is allowed to flow on to a revolving table placed above a cistern of water; the revolution of the table scatters the stream of molten iron, which falls in a shower of small globules into the water. Now, if we take 500 tons of this fine shotted metal, and well mix it together, we may obtain 2000 charges of 4 cwts. each, as uniform in quality as if taken from a fluid, each charge consisting of some millions of grains, only varying in extreme cases 1 or 2 per cent from each other, and in some cases not varying a tenth of 1 per cent, so that the mean of these millions of globules having a fractional part of 1 per cent variation, will give to each 4 cwts. taken from the mass a perfect identity of composition—and when it is considered that this shot is mixed with 25 times its weight of pure iron, the perfect uniformity in the results obtained will be fully appreciated. We may thus obtain 50,000 tons of steel of precisely the same degree of carburation, or we may vary the temper to any desired extent by simply varying the weight of shot added to a given quantity of pure iron. It must be borne in mind that the shotted metal is not melted in a furnace, but, when accurately weighed, it is put into a retort, where it is heated to a bright red, out of contact with the atmosphere, so that no oxydation or change in its composition takes place. When the malleable iron has been weighed, the shot is allowed

to descend through a pipe from the retort, and fall into the molten malleable iron, where its fusion is effected almost instantaneously. It has hitherto been the custom, when using a fluid carburet of iron, to assist the mixture by blowing for about half a minute through the metal; but this is a defective practice, inasmuch as the quantity both of manganese and carbon is affected by it to a small extent, and at the same time the air blown in increases the tendency of the metal to boil, and make unsound castings. In using the shotted metal in the ladle, a mechanical agitator is employed in lieu of the blast of air. It is shaped somewhat like a narrow two-bladed screw-propeller, coated with loam, and mounted at the lower end of a vertical shaft; the ladle full of steel is brought under the agitator, and is then raised so as to immerse it in the fluid; three or four minutes' rapid rotation in reverse directions produces a most perfect mixture of the metal, which is perfectly homogeneous; the agitator also uniformly cools the whole mass down to the temperature best adapted for casting. Previous to the introduction of the Bessemer process, large ingots of steel were almost unknown in this country. An ingot made by one of the largest steel manufacturers of Sheffield was shown in the exhibition of 1851, weighing 22 cwts., and was considered quite a *tour de force.* All cast-steel ingots were allowed at that time to become cold before forging, which never took place until the following day. The disadvantage of reheating ingots of several tons in weight is very great, for not only is a great deal of time and fuel lost in doing so, but on reheating the mass it follows that the exterior is always somewhat hotter and softer than the central part, and therefore the blows of the hammer do not operate sufficiently on the hard interior of the mass, while the soft exterior absorbs the whole force of the blow, and a most imperfect forging is the result. To obviate these difficulties Mr. Bessemer proposed to work the ingot soon after casting, and

when the central part of the mass was somewhat hotter and softer than the exterior; but this idea was in direct opposition to the received opinions of the trade, and it was pronounced impossible by so many "high authorities in such matters," that it was some time before he ventured to put it to a trial. If an ingot worth £100 was sure to fall to pieces at the first blow, it was clearly unwise to subject it to such an ordeal. Yet, on reflection, Mr. Bessemer states he was determined to try it, and from that moment has never discontinued to do so with all large masses, which are found to produce far more perfect forgings when so treated. For example, an ingot of 3 tons in weight, of about 5 feet in length by 20 inches square, will heat up a cold ingot mould to a bright red heat in 20 minutes. In 20 minutes more it may be removed from the mould, when its exterior surface will be found to have lost too much heat to render it fit for forging, while its centre will be too hot to work safely. The ingot is therefore put into a furnace where there is not much heat kept up, the object being to prevent loss of heat from the exterior surface, while enough of the central heat passes into it to render the whole workable. In about one hour the mass may be most advantageously treated under the hammer, the central part being still softer than the exterior, thus insuring a greater degree of soundness in the forging than could have been obtained had the ingot been allowed to cool down according to the old notions of the trade. In the manufacture of smaller masses of cast-steel, it is desirable to economise the heat derived from the converting process, and roll the ingots into the finished bar before allowing them to cool down. When 5 tons of steel are made into 20 ingots, of 5 cwts. each, for rolling into rails, no ordinary heating-furnace could hold them, and even if put into two or three separate heating-furnaces, some of them would be more exposed to the heat than others, causing both loss of time and injury to the metal. To

obviate this inconvenience, a circular furnace has been constructed, having a flat revolving bed, as shown in section at Fig. 62, where *n* is the bed of the furnace mounted on a vertical spindle, on which it revolves at the rate of one revolution every two minutes. Doors are made at each side, through one of which the red-hot ingots, as they are taken from the moulds, are placed on to the revolving bed, each one resting on its lower end, and a distance of 3 inches apart

Fig. 62.



from each other. The door on the opposite side of the furnace is provided for the removal of the ingots as required for the rolls. In this arrangement the most perfect equalization of heat is effected. The flame of the fire, which is made on the grate *m*, passes over the bridge and impinges on the outer sides of the circle of ingots, and passing between them as they come slowly round, again acts on the opposite side, which forms the interior of the circle of ingots, and passing again through the spaces between them, escapes by the flue *p*. By this means, a very small expenditure of fuel will suffice to keep 5 tons of these ingots all of the proper temperature for

the rolling-mill. In a large establishment, where this plan is being carried out, the molten metal from the blast-furnace is conveyed in a 12-ton ladle, mounted on wheels, to the converting house, where there are mounted six converting vessels, capable of producing 5 tons of steel each at a charge. The ingots will be worked while still hot from the converting process, and pass through every stage to the finished rail, before the red heat, originally acquired in the blast-furnace, leaves them. In the forging and shaping of large masses of wrought iron, the steam-hammer has been found of immense value. Indeed nothing could be better adapted for building up a large mass by the union of successive portions, since the *vis inertia* of the slabs to be welded on to the original core is not so great as to absorb the momentum of the falling hammer; hence a large proportion of the power it acquires in falling is transmitted to the surfaces intended to be united. But in the forging and shaping of large masses of cast-steel, all these favourable conditions are reversed, and the steam-hammer ceases to be an implement well adapted for the purpose. For example, in forging a marine engine-shaft of 20 inches in diameter and 30 feet long, a solid steel ingot of 3 feet square and 8 feet in length would be required, weighing over 15 tons. Now, such an ingot of metal would oppose the *vis inertia* of its mass to the momentum of the falling hammer just as the present anvil-block does, and, like it, would be little affected by the blow. To reach the central part of such a mass with sufficent force to elongate it, the force of the blow must be transmitted through a distance of 18 inches of solid metal, and the particles of this intervening mass must start from a state of perfect rest, and take up the speed which the hammer has acquired in falling. This, however, their *vis inertia* will prevent, and the result will be the absorption of the power before it reaches the centre; for in practice it is found that unless the hammer is of enormous weight, the exterior portion

of the mass is only elongated, and this causes either the tearing asunder of the central part, or the sliding of the exterior portion of metal over it, so as to form at the end of the shaft a cup of 1 or 2 feet in depth.

Hence it becomes apparent, that in working masses of cast-steel, the sudden impact of the hammer must be replaced by a powerful and steady pressure. The consolidation of a cast-steel ingot in a semi-fluid or solid state by means of hydrostatic pressure was patented by Mr. Bessemer in 1856, but little was done in that direction at this early period of the process. The subject was afterwards taken up by a Mr. Haswell of Vienna, who obtained results so satisfactory as to again excite attention to the subject. From the experiments made by Mr. Bessemer in the use of the hydraulic press, he became convinced of its importance as a substitute for the steam-hammer for working ingots of steel of all sizes; but the hydraulic press, as generally constructed, is simply an accumulator of small increments of force, its enormous power being given out slowly through a short distance, conditions certainly not favourable for acting on heated metal, where the maxim must always be "to strike the iron whilst it is hot." Bearing this trite proverb in mind, he has invented a hydraulic press of great power, which also operates with great rapidity, so that successive pressures may be given to a forging as rapidly as the blows of a steam-hammer. He has made several modifications of the press, adapting it to special purposes, such as forging, shearing, and punching metal. The leading feature of the invention will, however, be fully understood by referring to Fig. 63, which is a front elevation of the press. It consists of a large arched casting A, somewhat like the housing of a rolling-mill, the upper part being furnished with a powerful steel set screw B, which is made to move very freely in a steel box let into the head of the casting. Below the screw is a sliding block C, in which the upper hammer-

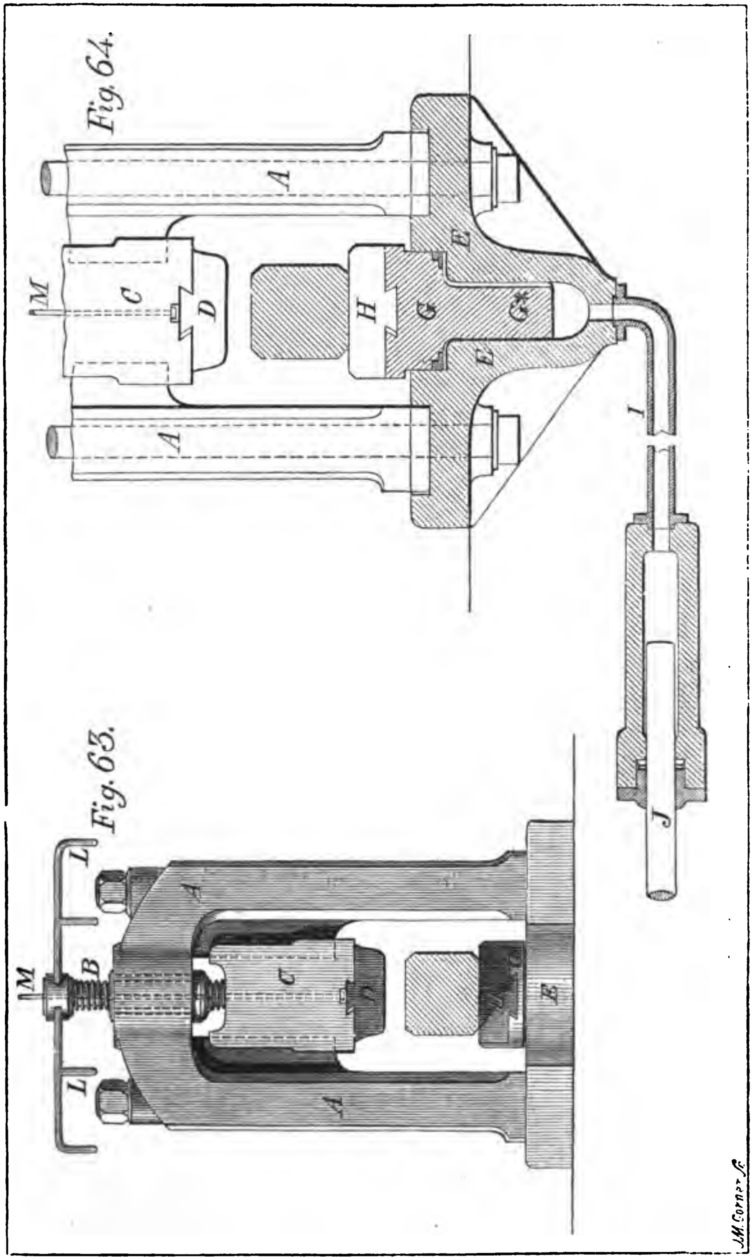


Fig. 64.

Fig. 63.

"face," or die, D, is fixed. In the lower part of the casting there is formed a hydraulic cylinder E, shown on a larger scale at Fig. 64. The ram G is fitted to this cylinder. The upper part of the ram carries the lower "hammer-face" or die H. Now it is intended that the rise and fall of the ram G shall be continuous. But it is only to move through a distance of 2 or 3 inches. The ram is made of two different diameters. The lower part G* is small and fits this part of the cylinder, and thereby guides the ram and keeps it steady. The upper part or head of the ram is of much larger diameter, but as its motion is but small, the cylinder is only made of 5 or 6 inches in depth although of 2 feet in diameter. Thus, the force tending to burst open the enlarged part of the cylinder is greatly reduced by the exceedingly short length of it subjected to pressure. A groove, formed on one side of the lower part of the ram, establishes a free communication between the lower part of the cylinder and the enlarged upper part, thus exposing the full area of the largest diameter of the ram to the pressure of the water. A pipe I leads from the lower part of the cylinder to a plunger J, which is actuated by a powerful engine. It will be observed that there are no valves of any kind interposed between the plunger J of the pump and the ram G; so that whenever the plunger J is made to reciprocate, a corresponding upward and downward motion will be given to the ram G, the latter moving a distance, as compared with the plunger J, equal to the difference in their respective areas. Now, if the movement of the ram G is 2½ inches, and the ingot to be operated upon fills the space left between the two dies or faces, within a distance of 2 inches, it follows that when the ram rises, a compression of the metal to the extent of half an inch will take place in the body operated upon. It will thus be seen that the force of the apparatus is only called into play during one-fifth part of the ascent of the ram, and not at all on its downward or

return stroke. The steam-engine which actuates the plunger J must be provided with a heavy fly-wheel of large diameter, so that the force of the engine may be accumulated in the fly-wheel during the inactive portion of the stroke of the ram, and be again given out when it is brought into action. The handles L are moved when required, and the exact guage of the forging is thus regulated to the greatest nicety. In order to enable the workman to move these handles very freely, a rod M passes upward through the screw and is fastened to the sliding block C; this rod passes upward to the roof, where it is jointed to a lever and counterweight, a little more than sufficient to support the entire weight of the screw and sliding block, and thus force them upward, by which means the screw will not only turn very freely from not having to lift the weight of the sliding block, but their pressing upward will prevent the concussion that would take place through lost space in the fittings, if they were not constantly forced upwards. In this apparatus, a rod or bar can be shaped as truly parallel as it could be made in an ordinary rolling-mill, and its exact diameter as easily regulated by the screw. It has been found that from 6 to 9 tons pressure on the square inch is sufficient to compress red-hot steel (depending on its temperature), and therefore that a ram of 24 inches in diameter will compress an area varying from 150 to 220 square inches in extent at each pulsation of the press, the compression being equal to half an inch over the whole area acted upon, an amount of duty scarcely equalled by the largest hammers in use. It will be observed that pressure so applied will not be confined to the surface of the forging, but will act throughout the whole mass, giving an equality and uniformity of structure, not to be attained by the hammer. The way in which the quiet pressure of the hydraulic apparatus acts throughout the mass, becomes very apparent by the following simple experiment:—take a plain cylindrical mass of steel 2 feet long and 8 or 10 inches in

diameter, place it on end under the hydrostatic press, and commence to operate upon it; it will then be found to become shorter and shorter, and to enlarge in the centre, and gradually assume the shape of a barrel, because the ends of it are cooled by contact with the metallic surfaces of the press, and it becomes more easy to compress at the central part than at the cooler part near the ends; but, if such a cylindrical mass of steel be placed under a steam-hammer, it will, after a few blows become enlarged at the upper end, and, by the reaction against the anvil, it also enlarges a little at the lower end, but the central parts remain almost unaltered. The cylinder assumes a form gradually tapering from both ends to the centre, and clearly showing how the action of the hammer gradually diminishes as we recede from the outer surface. The perfectly noiseless action of the press, and the absence of anything like concussion, render it much more easy of management and less fatiguing to the workmen than the hammer, while the small amount of foundation required tends to reduce the first cost, and fit it for situations where a powerful hammer could not be employed.

Among the requirements of the present day, the application of cast-steel to the manufacture of cannon-balls is likely to be of great importance. To facilitate this manufacture, Mr. Bessemer designed a rolling-mill, now in use at the works of Messrs. Bessemer and Co. of Sheffield, in which lumps of steel are fashioned into spherical balls, from 68 lbs. to 300 lbs. each in weight, with the greatest rapidity and with a degree of accuracy never attained in cast-iron shot. The mass to be operated upon is cut by a saw from a solid cylinder. The angles of the cylindrical lump are then reduced by pressure between curved surfaces. In this approximate form they are put at a bright red-heat into the rolling-mill, which consists simply of a revolving table in which an annular channel is formed. The channel being in section part of a circle of the

diameter of the intended shot, a similarly grooved table is fixed above it. The axis of the lower one may be moved endwise by an hydraulic ram, there being a recess formed in the ram to receive the end of the axis. Now, when a mass of steel is put into this annular channel, and the table set in motion by powerful gearing, the hydraulic ram is made to act on the lower end of the axis, and compress the revolving mass between the grooved surfaces. The lump of steel in its passage round the central shaft also revolves on its own axis, which constantly varies in position, and thus insures the most perfectly spherical form. To prevent the scale of the metal from roughening its surface, a jet of water passing down the hollow axis is projected against the shot as it revolves, and causes the scale to be thrown off as quickly as it is formed, while a blast of air passing down another passage in the axis blows all these detached scales out of the annular channel. Three balls are best acted upon at one time, so that in three or four minutes this simple apparatus is capable of producing three large spheres, more accurate in size and form than a workman with a slide-lathe could produce in as many days. The extraordinary tenacity of mild cast-steel made by the Bessemer process has been again exemplified in the trials of steel gun-barrels at the proof-house in Birmingham, in December 1863. The barrels were of the Enfield pattern, ·557 bore, bullet 715 grains, diameter ·551, length 1·043. These bullets were fired with 8¼ drachms of powder, commencing with one bullet, and repeating the firing with the additon of one more bullet at each discharge until the seventeenth round, when there were 16 bullets in the gun. The powder was then increased to 9¼ drachms, and the firing continued with 17 and then 18 bullets. The charge was again increased to 15 drachms of powder and 25 bullets, after which the barrels were examined, and found to be intact. Subsequently an Enfield barrel was made of this steel weighing only 1 lb.; this stood the Enfield proof; it was

then reduced a little at a time by turning off some of the metal in the lathe, and again fired from, until at last it was reduced to only 8 ounces in weight, when it still stood the Enfield proof without injury. These facts add another to the many proofs of the great tenacity of this metal. But a most important testing of its power to resist wear and abrasion has been given on the large scale by the London and North-Western Railway. In 1861, 500 tons of steel blooms, manufactured by Messrs. Bessemer and Co., were rolled into rails, at the Company's works at Crewe; the object being to subject them to the severest test by putting portions of them down on such parts of the line as were subject to the most rapid destruction, not only by the passage of the regular traffic, but where the stopping and starting and the making up of trains was constantly going on. The Crewe station offered a capital opportunity for this test, since the wear of rails on the two through lines at the station was so great, that good iron rails at this part of the line are worn out on both sides, and removed on an average three times in the year. On November 10th 1861, the double line of rails on each side of the Crewe station were laid in Bessemer steel, and in November 1864 not one of these had been turned or required turning. Indeed, there are no signs of wearing out. They are less round than they were on the top surface. Part of the metal has evidently been lost by abrasion, but not one crack or split is to be seen in any one of them, and it is difficult to say how many more years this first side of the rail will last. Another mode of testing was adopted at Camden station. At a part subjected to excessive wear here, a steel rail was placed opposite to an iron one, so that every train that passed subjected the iron rail and the steel rail to precisely the same amount of wear. These rails were inspected from time to time, and the results kept in a book of reference by an officer of the Company, from which the following facts were obtained :—

"Steel rail laid down on the goods line at the Camden station, on May 9th, 1862.—On examination of this rail at the end of September 1864, it exhibited but little signs of wear. It had not yet been turned over, the first face being still uppermost and in perfect working condition. On an average, 8000 goods-trucks have passed over it every 24 hours, and it is estimated that since it was first laid down, not less than 7,000,000 trucks have passed over it. The iron rail placed opposite to this steel one, in May 1862, was turned over in July, and worn out and replaced by a new rail on September 9th; this was turned over November 6th, and worn out and replaced on January 6th, 1863; this one was turned over on March 1st, and worn out and replaced on April 29th; it was turned on July 3d, and worn out and replaced September 29th; this, in like manner, was turned on December 16th, and worn out and replaced February 16th, 1864; this rail was turned on April 16th, and worn out and replaced on August 6th; this last rail was in use at the time when the steel rail was examined at the latter end of September 1864; while the steel one, placed opposite and subjected to such an extraordinary amount of traffic, was still free from any crack or signs of destructive wear, other than a small and gradual reduction of the weight of metal of which it was composed."

Results so important to the interests of the Company were not likely to be lost sight of. While these experimental trials with rails were going on, the employment of steel for plain and cranked axles, and wheel-tyres, and other parts of the locomotive engines, were made, and with results so satisfactory that the company resolved on erecting the extensive Bessemer steel works at Crewe, which have now been some months in active and successful operation, and which, when the whole of the machinery is up, will be capable of turning out 400 tons of steel per week, and furnishing all the metal required by the Company in their extensive rail, mill, and engine making establishment. In substituting steel for iron rails, a question of very grave importance arose, as to what was to be done with the old worn-out iron rails, which it is proposed to replace. Under the old system of rail-making, they were of considerable value, because they could be cut into short lengths, piled, and again rolled into railway bars. This question has, however, been satisfactorily solved, for Mr. Bessemer, who, in a recent patent, has shown how, by cutting

up the old wrought-iron rails, and heating them with the waste heat of the melting furnace, or by putting them at once into the converting vessel upon the fuel used to heat the vessel, after some ten minutes blowing, and when the rails are highly heated, the fluid pig-iron is run in among them. The enormous amount of surplus heat that may be generated by increasing the volume of the blast, will, in ten or fifteen minutes, melt down all the pieces of wrought-iron rails, which will form part of the charge of steel, without involving any extra cost in the process.

The practice which manufacturers of Bessemer steel have now had has shown the most favourable results as regards the loss of metal in the process, which, it will be remembered was at one time stated to be enormous. It appears, from the returns made by an eminent manufacturer, that a mean average, taken on the last 10,000 tons of Bessemer steel made by them, gave a difference of 12·49 per cent between the weight of crude pig-iron put into the melting-furnace, and the weight of steel ingots made from it; and of this there was a loss of ·66 per cent in the form of scrap-steel, so that the absolute loss was only 11·83 per cent. If, therefore, we assume the loss of pig-iron in the reverberatory melting-furnace to amount to 5 per cent, and that the carbon, silicium, etc., contained in the crude pig-iron amounted to another 5 per cent, we then have a loss of 1·83 per cent of iron, destroyed in the Bessemer process. The returns quoted are the most favourable yet made, but as they are taken on an actual production of 10,000 tons of steel, it shows to what a small item the loss of metal may be brought to, in skilful hands. If, therefore, we assume the loss in rolling these ingots into rails to be 3 per cent (exclusive of scrap-metal), we have 3 added to 12 = 15 per cent on the actual loss between the pig and the rail, in lieu of the 25 per cent in weight now lost in the manufacture of ordinary puddled iron rails.

In concluding these remarks, kindly furnished by Mr. Bessemer, I have to direct attention to the improvements that have lately been effected by this interesting process, and to follow briefly the progress which the system has made since its first announcement at Cheltenham. In the year 1855, Mr. Bessemer first tried his principle on a laboratory scale, by blowing air into 10 lbs. of molten iron contained in a crucible. At the latter end of 1856, he showed publicly the principle on a larger scale, 7 cwts. of crude metal being operated upon in a fixed vertical cylinder in which no fuel was employed. After this we have a lapse of time, during which he had to grapple with numerous practical difficulties, and during which period the process had become almost forgotten. In this interval of apparent inactivity, many steps were, however, gained in advance, and in November 1858, Mr. Bessemer and his partners had erected a steel works at Sheffield, and were employing a vessel mounted on axes, holding 12 cwt. of iron, and commenced making steel for sale. This first vessel soon gave place to one of a better construction holding 1 ton, and that in turn was replaced by a pair of vessels, each capable of making 1½ tons at a time. It then became evident that the process was much more easily effected in large than in small vessels, and towards the middle of the year 1860 the process began to attract some attention, and although the possibility of making steel by it was stoutly denied by many practical men, the firm of J. Brown and Co. was an exception, as they saw in it enough to warrant them in adopting it, and having convinced themselves of its utility, they set up a single vessel capable of making three tons of steel at a time. This apparatus was put to work in July 1861, and in the early part of 1862 they erected a second vessel of the same capacity. The successful working of Messrs. Bessemer and Co., and of Messrs. John Brown and Co., began rapidly to remove the prejudices of the trade, and both iron and steel manufacturers

obtained permission to use the process. Four extensive new companies were also formed expressly to carry it out, and the converting apparatus came into active operation at the works of several of the oldest established and most eminent iron and steel manufacturers, so that by the end of the year 1864 there were in England alone, erected and in course of erection, no fewer than 50 converting vessels, 2 of them having a capacity of 1½ tons, 12 of 3 tons, 6 of 4 tons, 28 of 5 tons, and 2 of 10 tons; which, together, are capable, when worked regularly, of producing 4550 tons of cast-steel weekly.

The rapid strides that are now making, and the importance of this increased power of production, will justify this detailed account of the process. And when it is known that the entire production of cast-steel in Great Britain in 1851 was, according to the report of the Commissioners of the International Exhibition, only 1000 tons per week, it will readily be conceived to what extent this new system of conversion may yet be carried for the extension of our national resources, and the advancement of constructive art.

It must be acknowledged that Mr. Bessemer has been a large contributor to our knowledge in dealing with iron in its crude state, so as to render it convertible into steel or refined iron direct from the pig. The only difficulty which appears to present itself in these very important operations is, to know the exact time at which the blast should be stopped in order to produce a certain quality of homogeneous iron or steel. This difficulty has been overcome to a certain extent by the general appearance of the flame, but Mr. Bessemer, finding that the eyesight of the furnace-men could not on all occasions be depended upon, adopted the method of refining the whole contents of the vessel by burning off the carbon, and then introducing a quantity of fluid iron from the reverberatory furnace containing the exact measure of carbon required for the iron or steel to be produced.

This ingenious method has been adopted with a certain amount of success, but it is still not perfect, as the boiling process has again to be renewed for the purpose of combination, and the correct time for arresting the blast still depends on the skill of the workmen.

To remedy these uncertainties my intelligent friend Professor Roscoe, of Owens College, Manchester, has directed his attention to this subject, and as an illustration of the application of abstract scientific principles to practical purposes, it may be stated, that the discoveries of Bunsen and Kirchhoff on spectrum analysis, in which Mr. Roscoe has taken an active part, were applied to the Bessemer furnace as a substitute for the eye of the workman. Mr. Roscoe's account of this application is highly interesting, and may be stated as follows:—

One of the great drawbacks to the successful practical working of Mr. Bessemer's beautiful process for converting cast-iron directly into steel, has been the difficulty of determining the exact point at which the blast of air passing through the molten metal is to be stopped. The conversion of five tons of cast-iron into cast-steel usually occupies from fifteen to twenty minutes, according to the varying conditions of weather, quality of the iron, strength of the blast, etc. If the blast be continued for ten seconds after the proper point has been attained, or if it be discontinued ten seconds before that point is reached, the charge becomes either so viscid that it cannot be poured from the converting vessel into the moulds, or it contains so much carbon as to crumble under the hammer. Up to the present time, the manufacturer has judged of the condition of the metal by the general appearance of the flame which issues from the mouth of the converting vessel. Long experience enables the workman thus to detect, with more or less exactitude, the point at which the blast must be cut off. It appeared to Mr. Roscoe that an examination of the spectrum

of this flame might render it possible to determine this point with scientific accuracy, and that thus an insight might be gained into the somewhat complicated chemical changes which occur in this conversion of cast-iron into steel. At the request of Messrs. John Brown and Co., of the Atlas Works, Sheffield, Mr. Roscoe investigated the subject, and succeeded in obtaining very satisfactory and interesting results. The instrument employed was an ordinary Steinheil's spectroscope, furnished with photographic scale and lamp, and provided with a convenient arrangement for directing the tube carrying the slit towards any wished-for part of the flame, and for clamping the whole instrument in the required position. By help of such an arrangement the spectrum of the flame can be most readily observed, and the changes which periodically take place can be most accurately noted.

The light which is given off by the flame in this process is most intense; indeed a more magnificent example of combustion in oxygen cannot be imagined; and a cursory examination of the flame spectrum in its various phases reveals complicated masses of dark absorption bands and bright lines, showing that a variety of substances are present in the flame in the state of incandescent gas. By a simultaneous comparison of these lines in the flame spectrum with the well-known spectra of certain elementary bodies, the presence of the following substances in the Bessemer flame, viz., sodium, potassium, lithium, iron, carbon, phosphorus, hydrogen, and nitrogen, was detected.

A further investigation, with an instrument of higher dispersive and magnifying powers than that employed, will doubtless add to the above list; and an accurate and prolonged study of this spectrum will probably yield very important information respecting the nature of the reactions occurring within the vessel. Already the investigation is so far advanced that the point in the condition of the metal at which it has

been found necessary to stop the blast can be ascertained with precision; and thus, by the application of spectrum analysis, that which previously depended on the quickness of vision of a skilled eye has become a matter of exact scientific observation.

Of the Bessemer system of manufacture we have given an elaborate description, as far as the limits of this work will permit. We have done this from the conviction that it is calculated to establish a new era in the manufacture of iron and steel—if it does not ultimately tend to convert nearly the whole process of manufactured iron into this superior kind of metal. In the performance of this duty we must not, however, neglect to acknowledge what is due to Mr. Mushet, another distinguished metallurgist, to whose skilful manipulation and analysis both Mr. Bessemer and the country are, in some measure, indebted for the success these new and important operations have obtained. From the changes now in progress we have only to instance that Mr. Mushet was the first to show the advantages of manganese in combination with the boiling process; and his titanium patents, from which he has derived no benefit, have been of great importance in the manufacture of iron and steel. These discoveries have never yet been acknowledged as they ought to have been, and I have much pleasure in directing public attention to the fact that Mr. Mushet's labours, under severe pecuniary pressure and ill-health, have been of great importance to practical science, and may safely be appreciated by every manufacturer of iron and steel.

CHAPTER IX.

THE PRODUCTION OF STEEL.

DURING the last twenty years a movement in advance of old customs has been going on in the manufacture of iron and steel, of so important a character as almost to constitute a revolution in the processes of conversion of crude pigs into malleable iron and steel. Since the introduction of the hot-blast there has been no important improvement in the reduction of the ores, nor is any great amount of saving likely to be effected in that process. But as regards the conversion of the iron into the malleable state, and into the varieties of steel, very important improvements have been effected during a period extending back not more than fifteen or twenty years. This is especially true of the processes for the manufacture of steel, in which the crude iron, having first been deprived of carbon in the refinery and puddling furnace, was again carbonised by being immersed in a hot bed of charcoal for a week or a fortnight. Recently it has been attempted to substitute for this roundabout method one in which the crude iron should be converted directly into steel by depriving it of its excess of carbon. This has been done in the puddling-furnace, by staying the process of decarburisation at the point at which the metal retains 1 or 1·5 per cent of carbon, and it has also been effected by introducing currents of air in the manner described in the last chapter. To a careful study of metallurgic chemistry, and repeated mechanical tests, we are indebted for these discoveries. These, united to more perfect machinery,

have already largely affected our iron manufacture, and seem likely to benefit the country and our widely-extended commerce. To Mr. Bessemer, amongst others, we owe the movement in this direction; and although he has not yet accomplished all he promised at the Meeting of the British Association at Cheltenham, he nevertheless set others to work as well as himself, and by indomitable perseverance and skill, he has probably done more for the new process than any one else since the days of Cort.

Notwithstanding the work—the good work—which has already been accomplished, we are still far short of that degree of perfection necessary to produce the finer qualities of iron and steel with certainty and effect. It is true that the last nine or ten years have effected wonderful improvements in the production and quality of iron and steel, but we are still defective in the means of producing the same quality continuously from the same ore and fuel. For example, an order is given for a quantity of steel or iron plates, with regard to which it is essential that the whole should be as nearly as possible uniform in strength and character, and that none of the plates should be under a certain standard tenacity. It is true that numerous samples will reach the standard; but, on the other hand, one plate in a hundred of inferior quality, if not detected, may, when introduced into some constructions, lead to disastrous consequences, and condemn the whole manufacture. In reference, therefore, to the improvements now in progress, it is essential to the interests of the iron trade that the manufacturers should study uniformity in the character of the article produced, in order that it may be raised to a high standard of excellence, in which the manufactures of this country should stand conspicuous.

Steel is a carburet of iron containing a less proportion of carbon than cast-iron by smelting. The latter, it has been seen, contains 4 or 5 per cent of carbon, whilst in steel the

proportion is only 0·5 to 1·5 per cent. Hence the direct method of obtaining steel is obviously to deprive the crude pig-iron of a part of its carbon, to reduce its amount to the requisite proportion. This direct method has already been described in the previous chapter. On the continent, and recently in this country, a modification of the puddling process is employed for the same purpose. But, notwithstanding many advantages of directness and economy, it is not yet the process most generally adopted.

In fact, the usual process, hitherto, has been the reverse of this: wrought-iron bars of the finest quality are selected, and the necessary carbon is imparted to them by "*cementation*." In this way the purest steel is obtained. The cast-iron for this purpose must be obtained from pure ores and smelted with pure fuel; and the puddling process by which the wrought-iron bars are produced tends to eliminate injurious alloys. Thus manufactured, the iron is in the best condition for manufacturing a pure steel, capable of taking the finest edge and the greatest degree of hardness.

I. THE PROCESS OF CEMENTATION.

To obtain steel by this process the purest wrought-iron bars are selected, foreign bars being preferred. Down to a recent period, Swedish and Russian bars were almost exclusively employed, notwithstanding their high price; these, smelted by charcoal, have a manifest superiority over all the irons of this country, where the ores are poorer and the charcoal scarcely to be obtained. These irons, therefore, are still preferred by the steel manufacturer, being employed where fine qualities are required. For inferior purposes, spring steel, etc., some English wrought-iron has of late been used with success.

The bars, selected with care, according to the steel to be produced, are broken into convenient lengths, and placed in

layers in pots mixed with and surrounded by charcoal. These pots are subjected to an intense heat, by which the carbon is vaporised, and gradually penetrates the iron and combines with it. The heat is continued for from nine to eleven days, after which the bars are removed, and often present a blistered surface. Hence this quality is termed "blistered steel."

The furnace in which the cementation is effected is shown in Fig. 65; *a a* are the *pots* in which the steel is placed, 12 feet long and 3 feet square, composed of a refractory siliceous fire-stone or fire-brick. Two of these pots are placed side by side, with the grate *g*, of equal length, between them.

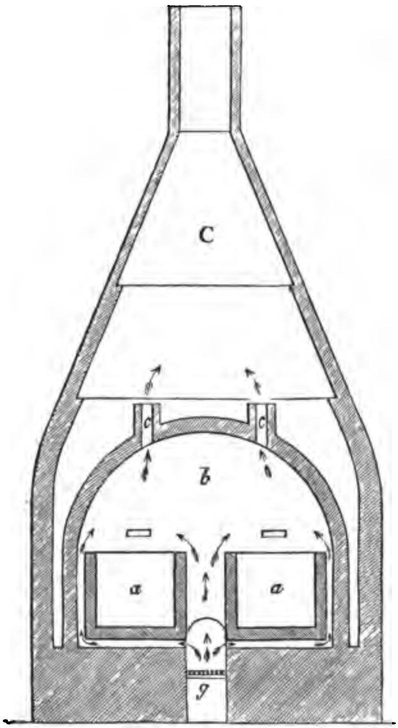


Fig. 65.

They need to be supported on massive foundations, to avoid sinking and fracture; and they are arched over by fire-brick in such a manner that the flame passes between, under and around them on every side. In the arch covering them, there are openings, *c c*, into the lofty dome-shaped chimney C, which covers all. The pots hold during each heat 15 or 16 tons of iron, and fourteen or sixteen heats are obtained in each per annum.

In filling these pots, the converter gets into the pot and spreads a layer of charcoal over the bottom. His assistant

then hands him in the bars, which he spreads in an even layer, making allowance for expansion. Over them is spread a layer of charcoal dust, and then a second layer of bars, and so on till the pot is filled; a layer of four or five inches of loam or wheelswarf is rammed over all, and the pot is ready for heating.

Each chest has an opening in which test-bars are laid, so that they can be withdrawn during the process of cementation, and the amount of carburisation ascertained. The appearance of the test-bars is a sufficient guide to a skilful converter as to the degree of carburisation which has been effected.

The steel thus obtained is known as *blister steel;* the bars, from the nature of the process, are hardest outside, and are therefore unfit for immediate use, except for a few purposes, such as for files, shovels, etc.

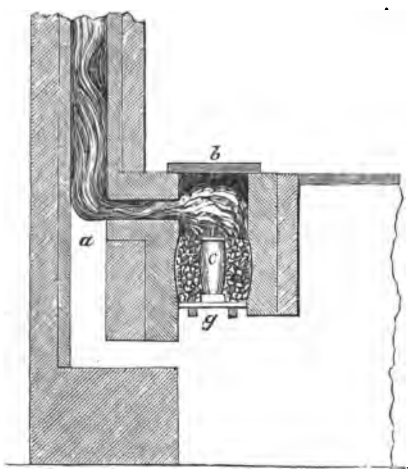


Fig. 66.

Cast-Steel consists of the bars of blister steel broken up and placed in crucibles, melted and cast into ingots. The crucibles are placed in a simple melting furnace, holding six, twelve, or more pots, a cross section of which is shown in Fig. 66; *g* is the grate, *c* the crucible with its cover, *a* the chimney-stack, *b* a loose cover over the opening in the furnace, through which the pots are inserted and withdrawn. The pots having been placed in position, and raised to a white heat, the blister steel is inserted, the cover put on, and the furnace filled up

with coke. When the steel is melted the pots are withdrawn, and the steel poured into cast-iron ingot-moulds. The pots are replaced in the furnace, and receive a second and third charge, after which they are thrown aside. The steel thus obtained is very homogeneous, all the irregularities of carburisation of the blister steel having been got rid of by fusion. The ingots are worked under the tilt-hammer to the required shapes and sizes.

Shear Steel is blister steel cut up, piled, and welded under the tilt-hammer, the piling answering the same purpose as fusion, but less perfectly, in producing homogeneity of structure.

Double Shear Steel is single shear steel a second time cut up, piled, heated, and tilted.

Fluxes are sometimes put with the blister steel into the crucible in making cast-steel. Chloride of sodium has been used by Mr. Mushet and others, with a view of purifying the metal. Binoxide of manganese has also been used, though makers are not agreed as to the part it plays in the process. Steel obtained from manganiferous ores is known to be of a fine quality, but this does not appear to result from the retention of the manganese in the steel. "The most satisfactory explanation of the beneficial effect of manganese is afforded by the protracted treatment to which it is found necessary to submit iron containing much of that metal, in order to effect its proper decarbonisation, and the facility thus afforded for its complete purification."—(ABEL.) Mr. Heath's process, celebrated as having been contested in every superior court in this country, is to introduce carburet of manganese into the crucible with the blister steel; but the carburet may be found in the crucible by introducing oxide of manganese and coal-tar. Metallic manganese has been used by Mr. Mushet to correct red shortness or cold shortness in steel.

II. HOMOGENEOUS IRON.

For some purposes, cast-steel is produced from wrought-iron by fusion with carbon in a crucible. For this purpose, foreign selected bars are cut up and introduced into the crucible in the ordinary steel melting furnace, Fig. 66, along with a small quantity of charcoal, which, during fusion, combines with the iron. The hardness of the steel depends upon the quantity of charcoal introduced. For tool steel, 1·5 to 1·7 per cent is introduced; for a soft steel for engraving purposes, Mr. Hurst of Ramsbottom introduces less than one per cent of charcoal with the iron, and the resulting metal is soft, receives a high polish, and case-hardens without bending. This steel, or partially carburised iron, I have tested, and found to sustain a strain of 35 tons to the inch. The temperature of fusion is much higher than in melting steel, and the pots wear out correspondingly fast. A Sheffield firm have also introduced a mild steel of this kind to a considerable extent, under the name of homogeneous iron. I have found this material to take an average tensile strain of 41¼ tons, or double that of wrought-iron.

III. M. CHENOT'S PROCESS.

M. Chenot's works, or rather those of M. Bugeney and Co., are in the immediate neighbourhood of Paris; and having visited them on two different occasions, I have less hesitation in giving a brief statement of this peculiar process, so far as I could gather it from M. Chenot and his son, who have the management of the works.

M. Chenot makes steel direct from the ore by converting it into a substance he calls *sponge*, in a peculiarly constructed furnace, 50 feet high and about 18 feet square at the widest part. To this furnace are attached other furnaces which con-

tain the fires, and great care is taken that only the gaseous products of combustion come in contact with the ores. The large furnace is constructed with numerous intersecting flues to distribute the heated currents from the attached furnaces, and to equalise the temperature at those parts where they come in contact with the ores.

It requires five days to convert the ore into sponge, and every twenty-four hours 18 cwts. or a ton are withdrawn from the furnace by a movable grated platform, which rises by rack and pinions, to the requisite height in the furnace, where it receives the charge, and is lowered at the required temperature to the space prepared for its reception below. Great care is taken to shut out the air by a luting of sand and clay all round the platform over which the sponge is removed from the furnace.

The ore being thus calcined or converted into sponge, it is allowed to soak in oil or any other fatty substance calculated to supply it with carbon. After this it is placed in wrought-iron retorts, and exposed for a couple of hours to the heat of a furnace in order to carry off any excess of carbon which it may have received. The sponge is next reduced to powder, and then compressed by machinery into bars in strong iron tubes. In this state it is fit for melting, and being placed in a crucible, with four tons of coke to one of steel, it is thence run into ingots. Lastly, it is prepared for the market in the usual way under the hammer. On the quality of this manufacture I can speak with some certainty, having brought several specimens home with me; and, judging from these, I can safely pronounce the Chenot manufacture a superior description of steel.

IV. PROCESS OF CAPTAIN UCHATIUS.

In this process cast-steel is produced direct from crude iron. The pigs are melted in a cupola, whence they are run

into a cistern of cold water, and granulated by striking a rapidly-revolving dash wheel. The finely-divided particles thus obtained are mixed with pulverised oxide of iron, or sparry iron and fine clay ; these having been intimately mixed, are introduced into a crucible and fused in the steel melting furnace. The granules of cast-iron, surrounded by rich oxides, yield up part of their carbon, and a slag is formed which purifies the steel. Part of the oxides are reduced, so that the quantity of steel obtained exceeds by 6 per cent the cast-iron introduced.

The degree of hardness of the resulting cast-steel depends in a great measure on the size of the granules, the smallest granules producing the softest steel, because the decarburisation proceeds very slowly inwards from the surface. The oxidising materials employed in the crucible are either very rich hæmatite ores or pure spathose ores finely pulverised, 20 or 30 per cent being introduced according to the amount of oxygen required.

V. GERMAN REFINING PROCESSES.

In Styria, Carinthia, Thuringia, and other parts of the Continent, steel is produced from crude iron by the decarburising effect of a blast in a furnace similar to a refinery. The pigs are melted by charcoal, and a strong blast allowed to play over the molten surface. The converter stirs up the iron to bring fresh portions under the action of the blast, until he judges, by the consolidation of the mass and the colour of the flame, that the process has been carried far enough.

VI. PRODUCTION OF STEEL BY PUDDLING.

For thirty years past it has been well known that steel could be produced direct from cast-iron in the puddling-

furnace by stopping the process of decarburisation before the whole of the carbon had been eliminated; but it is only recently that the manufacture has assumed much commercial importance. The furnace employed is similar to that figured at page 106 for puddling iron, or may be constructed with hollow cast-iron blocks, through which a circulation of water is maintained, surrounding the hearth, and with an extra chamber for heating the pigs, as shown in Figs. 67 and 68.

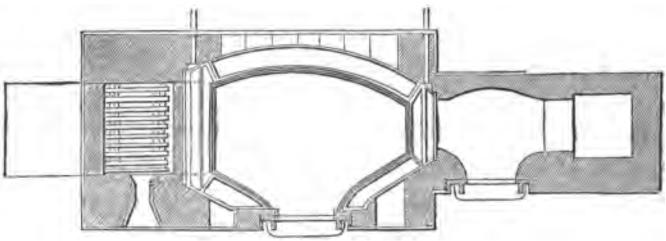


Fig. 67.

The method of operating is similar to that for puddling iron, already described; the difference being that in the latter case the molten iron is exposed to the oxidising action of the flame, until as far as possible the whole of the carbon originally in it is eliminated, whilst in the production of puddled steel the process is stopped before that point is reached, and whilst the iron retains from ½ to 1 per cent of carbon. It is only by experience that the puddler learns by the appearance of the grains, the consolidation of the mass, and the colour of the flame, the precise condition of carburisation of the materials in the furnace. When this knowledge has been attained, various qualities of steel, softer or harder, can be produced at will with great certainty. As soon as the desired degree of carburisation is reached, the damper is shut, the steel collected into balls, and hammered and rolled in the usual way. The bars thus obtained may be broken and the fractures examined, in order that any mistakes in the manufacture may be corrected

by the rejection of bad bars. The selected bars are then piled, heated, and rolled into bars or plates as may be required.

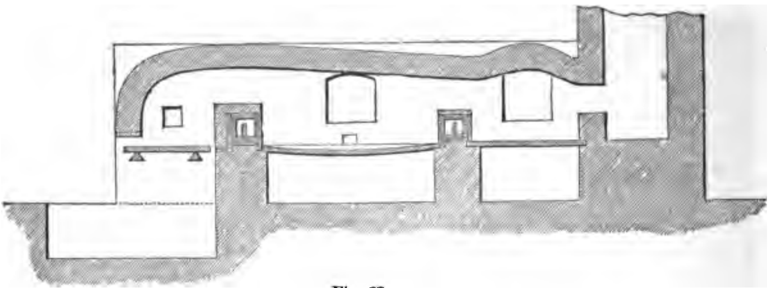


Fig. 68.

By a careful superintendence of the manufacture, and the selection of proper iron for the process—the North Welsh, Hæmatite, and best Scotch brands being preferred—a tough malleable steel is produced, unfit for cutting instruments, but capable of replacing wrought-iron in many constructions where strength and lightness are desired. It has been introduced already to a considerable extent in boiler-making and ship-building, and attempts have been made to apply it to bridges. The milder qualities have a tenacity of 35 tons per square inch, and the harder qualities rather above 40 tons per square inch. Its cost is about 25 per cent greater than that of wrought-iron, owing to a somewhat greater difficulty in working it under the hammer and in the rolls.

VII. MR. MUSHET'S PROCESS.

I have had an opportunity of testing the strength of some specimens of gun-metal produced by Mr. Mushet, which belong rather to the class of steel than of iron, and the results of which are given in the next chapter. The process by which this metal is produced is not known, but the following particulars have been communicated by Mr. Mushet.

Bar-iron is cut up into pieces of about one ounce weight. These are melted in steel melting-pots, with a small proportion of two other metals, from which the gun-metal derives its peculiar properties. The hardness of the alloy is regulated by adding a certain proportion of charcoal. After fusion the alloy is poured into moulds, and a bloom or ingot of gun-metal is obtained.

The softer varieties can be welded like cast-steel, but not the harder varieties, and its tenacity in all cases is impaired by raising it to a welding temperature. It ought therefore to be rolled or drawn out at a cast-steel heat.

CHAPTER X.

THE STRENGTH AND OTHER MECHANICAL PROPERTIES OF CAST AND WROUGHT IRON AND STEEL.

IN this section we have to consider the tensile and transverse strengths and powers of resisting compression of cast and malleable iron, as determined by direct experiment upon specimens of the material; and also to examine whether, as has been alleged, the hot-blast process injures the tenacity of the metal.

CAST-IRON.

The following tables give the results of experiments undertaken by Professor Hodgkinson and myself, at the request of the British Association, to determine the tensile and transverse strengths of cast-iron derived from the hot and cold blast. The castings for ascertaining the tensile strain were made very strong at the ends, with eyes for the bolts to which the shackles were attached; the middle part, where it was intended that the specimen should break, was cast of a cruciform + transverse section. The four largest castings were broken by the chain-testing machine belonging to the Corporation of Liverpool, the other by a lever.

TABLE I.—*Results of experiments on the Tensile Strength of Cast-iron.*

Description of Iron.	Number of Experiments.	Mean strength per square inch of section. lbs.	tons. cwts.
Carron iron, No. 2, hot-blast . .	3	13,505	6 $0\frac{1}{2}$
" " cold-blast . .	2	16,683	7 9
" No. 3, hot-blast . .	2	17,755	7 $18\frac{1}{2}$
" " cold-blast . .	2	14,200	6 7
Devon (Scotland) iron, No. 3, hot-blast	1	21,907	9 $15\frac{1}{2}$
Buffery iron, No. 1, hot-blast . .	1	13,434	6 0
" " cold-blast .	1	17,466	7 16
Coed Talon (North Wales) iron, No. 2, hot-blast . .	2	16,676	7 9
Do. do. cold-blast .	2	18,855	8 8

From the same series of experiments we select the following tables, giving the results obtained in regard to the resistance opposed to compression by cast-iron. The specimens employed were cylinders and prisms of various dimensions, and having their faces turned accurately parallel to each other and perpendicular to the axis of the specimen. They were crushed by a lever between parallel steel discs.

TABLE II.—*Weights required to crush Cylinders, etc., of Carron Iron, No. 2, Hot-blast.*

Diameter of Cylinder in parts of an inch.	Number of Experiments.	Mean Crushing Weight. lbs.	Mean Crushing Weight per square inch. lbs.	General Mean per square inch.
$\frac{1}{4}$	3	6,426	130,909	121,685 lbs. = 54 tons $6\frac{1}{2}$ cwts.
$\frac{3}{8}$	4	14,542	131,665	
$\frac{1}{2}$	5	22,110	112,605	
$\frac{16}{25} = \cdot 64$	1	35,888	111,560	
Prism, base ·50 inch square .	3	25,104	100,416	100,738 lbs. = 44 tons $19\frac{1}{2}$ cwts.
Prism base 1·00 × ·26 . .	2	26 276	101,062	

TABLE III.—*Weights required to crush Cylinders, etc., of Carron Iron, No. 2, Cold-blast.*

Diameter of Cylinder in parts of an inch.	Number of Experiments.	Mean Crushing Weight.	Mean Crushing Weight per square inch.	General Mean per square inch.
		lbs.	lbs.	
$\frac{1}{4}$	2	6,088	124,023	125,403 lbs. = 55 tons 19½ cwt.
$\frac{3}{8}$	4	14,190	128,478	
$\frac{1}{2}$	7	24,290	123,708	
Equilateral triangle, side ·866	2	32,398	99,769	100,631 lbs. = 44 tons 18½ cwts.
Squares, side ½ inch . . .	2	24,538	98,152	
Rectangles, base 1·00 inch × ·243	3	26,237	107,971	
Cylinders, ·45 inch diameter and ·75 inch high .	2	15,369	96,634	

TABLE IV.—*Results of experiments to ascertain the Force necessary to crush short Cylinders, etc., of Cast-iron, from various parts of the United Kingdom.*

Description of Iron.	Number of Experiments.	Mean Crushing Weight per square inch.	
		lbs.	tons. cwts.
Devon (Scotch) iron, No. 3, hot-blast	2	145,435	64 18½
Buffery iron, No. 1, hot-blast . .	4	86,397	38 11¼
„ „ cold-blast .	4	93,385	41 13½
Coed Talon, No. 2, hot-blast . .	4	82,734	36 18½
„ „ cold-blast . .	4	81,770	36 10
Carron iron, No. 2, hot-blast . .	2	108,540	48 9
„ „ cold-blast . .	3	106,375	47 9¾
Carron iron, No. 3, hot-blast . .	3	133,440	59 11¼
„ „ cold-blast . .	4	115,442	51 10¾

The specimens of Carron iron in Table IV. were prisms whose base was $\frac{3}{4} \times \frac{1}{3} = \frac{1}{4}$ square inch, and whose height varied from ½ inch to 1 inch. The other specimens were cylinders

whose diameters were about ½ inch, and height varied from ½ inch to 2 inches.

From the above experiments, Mr. Hodgkinson concludes that "where the length is not more than about three times the diameter, the strength for a given base is pretty nearly the same." Fracture took place either by wedges sliding off (Fig. 69), or by the top and bottom forming pyramids, and forcing out the sides (Fig. 70); and the angle of the wedge is nearly constant, a mean of 21 cylinders being 55° 32.′

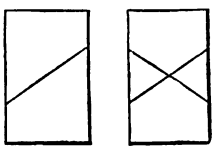


Fig. 69. Fig. 70.

From the same series of experiments I give the results obtained by myself, in regard to the effects of time and temperature. The bars employed were cast to be 1 inch square, and 4 feet 6 inches long, and were loaded with permanent weights as under; the deflections being taken at various intervals during a period of fifteen months. Coed Talon hot and cold blast iron was employed.

TABLE V.—*The Effect of Time on Loaded Bars of Hot and Cold Blast Iron, in their Resistance to a Transverse Strain.*

Permanent load in lbs.	Increase of Deflection of Cold-blast bars.	Increase of Deflection of Hot-blast bars.
280	·033	·043
336	·046	·077
392	·140	·088
449	·047	
Mean.	·066	·069

It has been assumed by most writers on the strength of materials, that the elasticity of cast-iron remained perfect to the extent of one-third the weight that would break it. This is, however, a mere assumption, as it has been found that the elasticity of cast-iron is injured with less than one-half that

weight; and the question to be solved in the above experiments was, to what extent the material could be loaded without endangering its security; or how long it would continue to support weights, varying from one-half to one-tenth of the load that would produce fracture. These experiments were continued from six to seven years, and the results obtained were, that the bars which were loaded to within one-tenth of their breaking weight would have continued to have borne the load, in the absence of any disturbing cause, *ad infinitum;* but the effect of change, either of the same or a lighter load, led ultimately to a fracture.

From these facts it is deduced, that so long as the molecules of the material are under strain (however severe that strain may be), they will arrange and accommodate themselves to the pressure; but with the slightest disturbance, whether produced from vibration or the increase or diminution of load, it becomes, under these influences, only a question of time when rupture ensues.

In the following experiments on the relative strengths of Coed Talon hot and cold blast iron to resist transverse strain at different temperatures, the results are reduced to those of bars 2 feet 3 inches between supports, and 1 inch square.

From this table it will be seen "that a considerable failure of the strength took place after heating the No. 2 iron from 26° to 190°. At 212°, we have in the No. 3 a much greater weight sustained than by No. 2 at 190°; and at 600° there appears, in both hot and cold blast, the anomaly of increased strength as the temperature is increased."* The following results are, with one exception, in favour of the cold-blast, as far as strength is concerned; and in favour of the hot-blast, with one exception, as regards power of resisting impact.

* This probably arises from the greater ductility of the bars at an increased temperature.

TABLE VI.—*Effect of Temperature on the Transverse Strength of Cast-iron.*

	Temperature Fahr.	Specific Gravity.	Modulus of Elasticity.	Breaking Weight.	Ultimate Deflection.	Power of resisting impact.
Cold-Blast, No. 2	27°	6·955	12,799,050	874·0	·4538	397·7
„	32	6·955	14,327,450	949·6	·402	382·4
„	113	6·955	14,168,000	812·9	·336	273·1
Hot-Blast, No. 2	20	6·968	14,902,900	811·7	·4002	325·0
„	32	6·968	14,003,350	919·7	·429	395·0
„	84	6·968	14,500,000	877·5	·421	369·4
Cold-Blast, No. 2	192	...	14,398,600	743·1	·301	223·7
No. 3	212	...	...	924·5		
„	600	...	...	1033·0		
No. 2	Red by daylight	...	...	663·3		
„	Red in dark	...	...	723·1		
Hot-Blast, No. 2	136	...	13,046,200	875·7	·389	34 0·6
„	187	...	11,012,500	638·8	·359	22 9·3
„	188	...	13,869,500	823·6	·363	29 8·9
No. 3	212	...	...	818·4		
„	600	...	...	875·8		
No. 2	Red in dark	...	...	829·7		

The following table gives the results of my own experiments on the transverse strength of rectangular cast-iron bars, each bar being reduced to exactly one inch square.

In the following abstract, the transverse strength, which may be taken as a criterion of the value of each iron, is obtained from the mean of the experiments first on the long bars, 4 feet 6 inches between the supports, and next on those of half the length, or 2 feet 3 inches between supports.

All the other values are deduced from the 4 feet 6 inches bars.

TABLE VII.—*General Summary of Results on Rectangular Bars, as obtained from nearly the whole of the British Ironworks.—"Manchester Memoirs," New Series, Vol V.*

No. of iron in the scale of strength.	Description of Iron.	No. of Experiments on each.	Specific Gravity.	Modulus of Elasticity in lbs. per square inch, or stiffness.	Breaking weight in lbs. of bars 4 ft. 6 in. between supports.	Breaking weight in lbs. of bars 2 ft. 5 in., reduced to 4 ft. 6 in. between supports.	Mean breaking weight in lbs. (S.)	Ultimate deflection of 4 ft. 6 in. bars in parts of an inch.	Power of the 4 ft. 6 in. bars to resist impact.	Colour.	Quality.
1	Ponkey, No. 3, cold-blast	4	7·122	17,211,000	567	595	581	1·747	992	Whitish grey.	Hard.
2	Devon, No. 3, hot-blast *	2	7·251	22,473,650	537	...	537	1·090	589	White.	"
3	Oldberry, No. 3, hot-blast	5	7·300	22,733,400	543	517	530	1·005	549	"	"
4	Carron, No. 3, hot-blast *	2	7·056	17,873,100	520	534	527	1·365	710	Whitish grey.	"
5	Eglinton, No. 4, from prepared coke†	6	...	...	515	...	515	1·460	751	Light grey.	Rather hard.
6	Beaufort, No. 3, hot-blast	5	7·069	16,802,000	505	529	517	1·599	807	Dullish grey.	Hard.
7	Butterley	4	7·038	15,379,500	489	515	502	1·815	889	Dark grey.	Soft.
8	Bute, No. 1, cold-blast	4	7·066	15,163,000	495	487	491	1·764	872	Bluish grey.	"
9	Windmill End, No. 2, cold-blast	4	7·071	16,490,000	483	495	489	1·581	765	Dark grey.	Hard.
10	Old Park, No. 2, cold-blast	5	7·049	14,607,000	441	529	485	1·621	718	Grey.	Soft.
11	Beaufort, No. 2, hot-blast	4	7·108	16,301,000	478	470	474	1·512	729	Dull grey.	Hard.
12	Lowmoor, No. 2, cold-blast	4	7·055	14,569,500	462	483	472	1·852	855	Dark grey.	Soft.
13	Buffery, No. 1, cold-blast *	5	7·079	15,381,200	463	...	463	1·550	721	Grey.	Rather hard.
14	Brimbo, No. 2, cold-blast	5	7·017	14,911,666	466	453	459	1·748	815	Light grey.	"
15	Apedale, No. 2, hot-blast	3	7·017	14,852,000	457	455	456	1·730	791	"	Stiff.
16	Oldberry, No. 2, cold-blast	4	7·059	14,307,500	453	457	455	1·811	822	Dark grey.	Rather soft.
17	Pentwyn, No. 2	4	7·038	15,193,000	438	473	455	1·484	650	Bluish grey.	Hard.
18	Maesteg, No. 2	5	7·038	13,959,500	453	455	454	1·957	886	Dark grey.	Rather soft.
19	Muirkirk, No. 1, cold-blast *	4	7·113	14,003,550	443	464	453	1·734	770	Bright grey.	Fluid.
20	Adelphi, No. 2, cold-blast	5	7·080	13,815,500	441	457	449	1·759	777	Light grey.	Soft.
21	Blania, No. 3, cold-blast	5	7·159	14,281,466	433	464	448	1·726	747	Bright grey.	Hard.
22	Devon, No. 3, cold-blast	4	7·285	22,907,700	448	...	448	0·790	353	Light grey.	"
23	Gartsherrie, No. 3, hot-blast	5	7·017	13,894,000	427	467	447	1·557	998	"	Soft.
24	Eglinton, No. 4, common coke	6	...	...	447	...	447	1·870	798	Dull grey.	Rather hard.
25	Frood, No. 2, cold-blast	5	7·031	13,112,666	460	434	447	1·825	511	Light grey.	Open.

26	Lane End, No. 2	3	7·028	15,787,666	444	...	444	1·414	629	Dark grey.	Soft.
27	Carron, No. 3, cold-blast	5	7·094	16,246,966	444	443	443	1·336	593	Grey.	,,
28	Dundyvan, No. 3, cold-blast	4	7·087	16,534,000	456	430	443	1·469	674	Dull grey.	Rather soft.
29	Maesteg (marked red)	5	7·038	13,971,500	440	444	442	1·887	830	Bluish grey.	Fluid.
30	Corbyns Hall, No. 2	5	7·007	13,845,866	430	454	442	1·687	727	Grey.	Soft.
31	Pontypool, No. 2	5	7·080	13,136,500	439	441	440	1·857	816	Dull blue.	Rather soft.
32	Walbrook, No. 3	5	6·979	15,394,766	432	449	440	1·443	625	Light grey.	Rather hard.
33	Milton, No. 3, hot-blast	4	7·051	15,852,500	427	449	438	1·368	585	Grey.	,,
34	Buffery, No. 1, hot-blast*	3	6·998	13,730,500	436	...	436	1·640	721	Dull grey.	Soft.
35	Level, No. 1, hot-blast	5	7·080	15,452,500	461	403	432	1·516	699	Light grey.	,,
36	Pant, No. 2	5	6·975	15,280,900	408	455	431	1·251	511	,,	Rather hard.
37	Level, No. 2, hot-blast	6	7·031	15,241,000	419	439	429	1·358	570	Dull grey.	Soft.
38	W. S. S., No. 2	5	7·041	14,953,333	413	446	429	1·339	554	Light grey.	,,
39	Eagle Foundry, No. 2, hot-blast	4	7·038	14,211,000	408	446	427	1·512	618	Bluish grey.	,,
40	Elsicar, No. 2, cold-blast	4	6·928	12,586,500	446	408	427	2·227	992	Grey.	,,
41	Varteg, No. 2, hot-blast	4	7·007	15,012,000	422	430	426	1·450	621	,,	Hard.
42	Coltham, No. 1, hot-blast	5	7·128	15,510,066	464	385	424	1·532	716	Whitish grey.	Rather soft.
43	Carrol, No. 2, cold-blast	4	7·069	17,036,000	430	408	419	1·231	530	Grey.	Hard.
44	Muirkirk, No. 1, hot-blast*	4	6·953	13,294,400	417	...	418	1·570	656	Bluish grey.	Soft.
45	Brierley, No. 2	5	7·185	16,156,133	406	...	418	1·222	494	Dark grey.	,,
46	Coed-Talon, No. 2, hot-blast*	4	6·969	14,322,500	409	424	416	1·882	771	Bright grey.	,,
47	Coed-Talon, No. 2, cold-blast*	5	6·955	14,304,000	403	418	413	1·470	600	Grey.	,,
48	Monkland, No. 2, hot-blast	3	6·916	12,259,500	402	404	403	1·762	709	Bluish grey.	,,
49	Ley's Works, No. 1, hot-blast	3	6·957	11,539,333	392	...	392	1·890	742	,,	,,
50	Milton, No. 1, hot-blast	4	6·976	11,974,500	353	386	369	1·525	532	Grey.	Soft and fluid.
51	Plas Kynaston, No. 2, hot-blast	5	6·916	13,341,633	378	337	357	1·366	517	Light grey.	Rather soft.

* The irons with asterisks are taken from the experiments on hot and cold blast iron made by Mr. Hodgkinson and Mr. Fairbairn for the British Association for the Advancement of Science. See Seventh Report, vol. vi.

The modulus of elasticity was usually taken from the deflection caused by 112 lbs. on the 4 feet 6 inch bars.

To find from the above the breaking weight in rectangular bars generally; calling b and d the breadth and depth in inches, and l the distance between the supports in feet; and putting 4·5 for 4 feet 6 inches, we have $\frac{4·5\, b\, d^2\, S}{l}$=breaking weight in lbs. The value of S being taken from the table above.

For example:—What weight would be necessary to break a bar of Lowmoor iron, 2 inches broad, 3 inches deep, and 6 feet between the supports? According to the rule given above, we have $b = 2$ inches, $d = 3$ inches, $l = 6$ feet, $S = 472$, by the table. Then

$$\frac{4·5 \times b\, d^2\, S}{l} = \frac{4·5 \times 2 \times 9 \times 472}{6} = 6372 \text{ lbs.}$$

† This iron was melted in the cupola, from coke entirely freed from sulphur, by Mr. Crace Calvert's process.

With regard to the comparative strengths of hot and cold blast iron, the following extracts from Mr. Hodgkinson's report, read before the British Association, give the general results of his experiments :—

TABLE VIII.—*Carron Iron, No.* 2.

	Cold-blast.	Hot-blast.	Ratio representing Cold-blast by 1 000.	
Tensile strength in lbs. per inch square . .	16,683 (2)	13,505 (3)	1000 : 809	
Compressive do. in lbs. per inch from castings torn asunder .	106,375 (3)	108,540 (2)	1000 : 1020	Mean 997.
Do. from prisms of various forms . .	100,631 (4)	100,738 (2)	1000 : 1001	
Do. from cylinders .	125,403 (13)	121,685 (13)	1000 : 970	
Transverse strength from all the experiments	(11)	(13)	1000 : 991	
Power to resist impact	(9)	(9)	1000 : 1005	
Transverse strength of bars 1 inch square in lbs.	476 (3)	463 (3)	1000 : 973	
Ultimate deflection of do. in inches . . .	1·313 (3)	1·337 (3)	1000 : 1018	
Modulus of elasticity in lbs. per square inch	17,270,500 (2)	16,085,000 (2)	1000 : 931	
Specific gravity . . .	7·066	7·046	1000 : 997	

TABLE IX.—*Devon Iron, No.* 3.

	Cold-blast.	Hot-blast.	Ratio representing Cold-blast by 1000.
Tensile strength . .	...	21,907 (1)	
Compressive do. . .	...	145,435 (4)	
Transverse do. from the experiments generally.	(5)	(5)	1000 : 1417
Power to resist impact	(4)	(4)	1000 : 2786
Transverse strength of bars 1 inch square .	448 (3)	537 (2)	1000 : 1199
Ultimate deflection do.	79 (2)	1·09 (2)	1000 : 1380
Modulus of elasticity do.	22,907,700 (2)	22,473,650 (2)	1000 : 991
Specific gravity . . .	7·295 (4)	7·229 (2)	1000 : 991

TABLE X.—*Buffery Iron, No.* 1.

	Cold-blast.	Hot-blast.	Ratio representing Cold-blast by 1000.
Tensile strength . .	17,466 (1)	13,434 (1)	1000 : 769
Compressive do. . .	93,366 (4)	86,397 (4)	1000 : 925
Transverse do. . . .	(5)	(5)	1000 : 931
Power to resist impact	(2)	(2)	1000 : 963
Transverse strength of bars one inch square	463 (3)	436 (3)	1000 : 942
Ultimate deflection do.	1·55 (3)	1·64 (3)	1000 : 1058
Modulus of elasticity do.	15,381,200 (2)	13,730,500 (2)	1000 : 893
Specific gravity . .	7·079	6·998	1000 : 989

TABLE XI.—*Coed-Talon Iron, No.* 2.

	Cold-blast.	Hot-blast.	Ratio representing Cold-blast by 1000.
Tensile strength . . .	18,855 (2)	16,676 (2)	1000 : 884
Compressive do. . . .	81,770 (4)	82,739 (4)	1000 : 1012
Specific gravity . . .	6·955 (4)	6·968 (3)	1000 : 1002

TABLE XII.—*Carron Iron, No.* 3.

	Cold-blast.	Hot-blast.	Ratio representing Cold-blast by 1000.
Tensile strength . . .	14,200 (2)	17,755 (2)	1000 : 1250
Compressive do. . . .	115,442 (4)	133,440 (3)	1000 : 1156
Specific gravity . . .	7·135	7·056 (1)	1000 : 989

Beginning with No. 1 iron, of which we have a specimen from the Buffery Ironworks, a few miles from Birmingham, we find the cold-blast iron somewhat surpassing the hot-blast in all the following particulars: direct tensile strength, compressive strength, transverse strength, power to resist impact, modulus of elasticity or stiffness, specific gravity, etc.; whilst the only numerical advantage possessed by the hot-blast iron

is, that it bends a little more than the cold-blast before it breaks.

In the irons of the quality No. 2, the case seems in some degree different; in these the advantages of the rival kinds seem to be more nearly balanced. They are still, however, rather in favour of the cold-blast.

So far as my experiments have proceeded, the irons of No. 1 have been deteriorated by the hot-blast; those of No. 2 appear also to have been slightly injured by it; while the irons of No. 3 seem to have been benefited by its mollifying powers. The Carron iron, No. 3, hot-blast, resists both tension and compression with considerably more energy than that made with the cold-blast; and the No. 3 hot-blast iron from the Devon Works, in Scotland, is one of the strongest cast-irons I have seen, whilst that made by the cold-blast is comparatively weak, though its specific gravity is very high, and higher than in the hot. The extreme hardness of the cold-blast Devon iron alone prevented many experiments that would otherwise have been made upon it, no tools being hard enough to form the specimens. The difference of strength in the Devon irons is peculiarly striking.

From the evidence here brought forward, it is rendered exceedingly probable that the introduction of a heated blast in the manufacture of cast-iron has injured the softer irons, whilst it has frequently mollified and improved those of a harder nature; and, considering the small deterioration that the irons of quality No. 2 have sustained, and the apparent benefit to those of No. 3, together with the great saving effected by the heated blast, there seems good reason for the process becoming as general as it has done.

The following table gives a summary of the relative compressive and tensile resistances of various descriptions of iron as they have been determined by Professor Hodgkinson :—

TABLE XIII.—*Tensile and Compressive Strength of various descriptions of Iron.*

Description of the Iron.	Tensile strength per square inch of section.	Height of Specimen.	Crushing strength per square inch of section.	Ratio of the powers to resist tension and compression.	
	lbs. tons.	inch.	lbs. tons.		Mean.
Lowmoor Iron, No. 1	12,694= 5·667	¾	64,534=28·809	1:5·084	1:4·765
		1½	56,455=25·198	1:4·446	
Lowmoor Iron, No. 2	15,458= 6·901	¾	99,525=44·430	1:6·438	1:6·205
		1½	92,332=41·219	1:5·973	
Clyde Iron, No. 1 .	16,125= 7·198	¾	92,869=41·459	1:5·759	1:5·631
		1½	88,741=39·616	1:5·503	
Clyde Iron, No. 2 .	17,807= 7·949	¾	109,992=49·103	1:6·177	1:5·953
		1½	102.030=45·549	1:5·729	
Clyde Iron, No. 3 .	23,468=10·477	¾	107,197=47·855	1:4·568	1:4·518
		1½	104,881=46·821	1:4·469	
Blaenavon Iron, No. 1	13,938= 6·222	¾	90,860=40·562	1:6·519	1:6·149
		1½	80,561=35·964	1:5·780	
Blaenavon Iron, No. 2, first sample	16,724= 7·466	¾	117,605=52·502	1:7·032	1:6·577
		1½	102,408=45·717	1:6·123	
Blaenavon Iron, No. 2, second sample	14,291= 6·380	¾	68,559=30·606	1:4·797	1:4·796
		1½	68,532=30·954	1:4·795	
Calder Iron, No. 1 .	13,735= 6·131	¾	72,193=32·229	1:5·256	1:5·394
		1½	75,983=33·921	1:5·532	
Coltness Iron, No. 3 .	15,278= 6·820	¾	100,180=44·723	1:6·557	1:6·611
		1½	101,831=45·460	1:6·665	
Brymbo Iron, No. 1 .	14,426= 6·440	¾	74,815=33·399	1:5·186	1:5·216
		1½	75,678=33·784	1:5·246	
Brymbo Iron, No. 3 .	15,508= 6·923	¾	76,133=33·988	1:4·909	1:4·936
		1½	76,958=34·356	1:4·963	
Bowling Iron, No. 2 .	13,511= 6·032	¾	76,132=33·987	1:5·635	1:5·555
		1½	73,984=33·028	1:5·476	
Ystalyfera Anthracite Iron, No. 2	14,511= 6·478	¾	99,926=44·610	1:6·886	1:6·735
		1½	95,559=42·660	1:6·585	
Yniscedwyn Anthracite Iron, No. 1	13,952= 6·228	¾	83,509=37·281	1:5·985	1:5·811
		1½	78,659=35·115	1:5·638	
Yniscedwyn Anthracite Iron, No. 2	13,348= 5·959	¾	77,124=34·430	1:5·778	1:5·712
		1½	75,369=33·646	1:5·646	
Mr. Morries Stirling's iron, denominated second quality	25,764=11·502	¾	125,333=55·952	1:4·865	1:4·751
		1½	119,457=53·329	1:4·637	
Mr. Morries Stirling's iron, denominated third quality	23,641=10·474	¾	158,653=70·827	1:6·762	1:6·149
		1½	129,876=57·980	1:5·536	

The next table gives a general summary of the results of my own experiments on the strength of iron after successive meltings. The iron used was Eglinton No. 3, hot-blast, and was melted eighteen times, three bars being cast at each melting. These bars, which were about 1 inch square

and 5 feet long, were placed upon supports, 4 feet 6 inches apart, and broken by a transverse strain. Cubes, from the same irons, exactly 1 inch square, were then crushed between parallel steel bars, by a large wrought-iron lever.

In the following Table XIV., the results on transverse strain are reduced to those on bars exactly 1 inch square and 4 feet 6 inches between supports.

Some curious and interesting results were obtained from a series of experiments on iron cast from repeated meltings, as exhibited in Tables XIV and XV.

TABLE XIV.—*Transverse Strength of Iron after successive Remeltings.*

No. of Meltings.	Specific gravity.	Mean breaking weight in lbs.	Mean ultimate deflection in inches.	Power to resist impact.	Mean crushing weight of inch cubes in tons.
1	6·969	490·0	1·440	705·6	41·9
2	6·970	441·9	1·446	630·9	
3	6·886	401·6	1·486	596·7	
4	6·938	413·4	1·260	520·8	
5	6·842	431·6	1·503	648·6	
6	6·771	438·7	1·320	579·0	
7	6·879	449·1	1·440	646·7	
8	7·025	491·3	1·753	861·2	
9	7·102	546·5	1·620	885·3	64·3
10	7·108	566·9	1·626	921·7	
11	7·113	651·9	1·636	1066·5	
12	7·160	692·1	1·666	1153·0	
13	7·134	634·8	1·646	1044·9	
14	7·530	603·4	1·513	912·9	
15	7·248	371·1	0·643	238·6	82·8
16	7·330	351·3	0·566	198·5	
17	lost.	...	...	...	
18	7·385	312·7	0·476	148·8	

From the above results it will be observed that the maximum of strength, elasticity, etc., is only arrived at after the metal has undergone twelve successive meltings. It is probable

that other metals and their alloys may follow the same law; but that is a question that has yet to be solved, probably by a series of experiments requiring a considerable amount of time and labour to accomplish, but which I venture to hope I may be able at some future time to undertake.

In the resistance of the different meltings from the same iron, to a force tending to crush them, we have the following results:—

TABLE XV.—*Compressive Strength of Iron after successive Remeltings.*

Number of meltings.	Resistance to compression per square inch, in tons.	Remarks.
1	44·0	
2	43·6	
3	41·1	
4	40·7	
5	41·1	
6	41·1	
7	40·9	
8	41·1	
9	55·1	
10	57·7	
11, 11	Mean 69·8	
12	73·1	In this experiment the cube did not bed properly on the steel plates, otherwise it would have resisted a much greater force.
13	66·0	
14	95·9	
15	76·7	
16	70·5	
18	88·0	

Nearly the whole of the specimens were fractured by wedges which split or slid off diagonally at an angle of from 52° to 58°.

The extraordinary resisting powers of bars cut from three specimens of cast-iron shot prepared by Dr. Price for experiment at Shoeburyness, to a tensile strain, are of that im-

portant character which requires careful investigation. In former times, when vessels were entirely constructed of wood, and when thick plates of armour were never dreamt of for purposes of resistance, cast-iron shot was equally good and effective in its results as the hardest steel. Now things are widely different, for instead of 18 to 20 inches thickness of oak, which is easily perforated, we have to go through a solid 4½ or 5 inch wrought-iron plate of the toughest description, before the interior of the ship is reached. In firing at timber-built vessels there is no injury done to cast-iron shot, whatever may be the thickness; but in iron-cased ships the injury done to cast-iron shot is much greater than that which it inflicts upon the plates. On referring to our former experiments, we find that a cast-iron shot breaks in pieces, and loses a considerable amount of its *vis viva* when it strikes at a high velocity against a thick wrought-iron plate, and in order to render it more tenacious and more destructive in its effects, it is equally important that the shot should be as irresistible as the plate should be invulnerable. It is true that we may never attain so important a desideratum in cast-iron as to make shot of that material indestructible; but we may, by proper attention to its mechanical and chemical elements, greatly improve its powers of resistance; and the following experiments on Dr. Price's compound mixture clearly show, as a beginning, what has been done, and what may yet be expected by a careful investigation of a subject of such great importance to the country, and of no small value as regards the improvement of projectiles.

The average tensile strength of cast-iron has been found to be about seven tons per square inch. In the first experiment on the metal from which this shot was cast, it appeared so much above the ordinary tenacity of cast-iron that another piece was cut out, near the centre, for the purpose of correct-

ing what appeared to be the anomalous condition of the first experiment. It will, however, appear obvious that the metal, taken as a measure of its tenacity, is, in the mean of the two experiments, considerably above that of ordinary cast-iron, being in the ratio of about 12 : 7, or as 1·77 : 1 in favour of the shot. The appearance of the fracture is a close finely-granulated structure, crystallization bright and clear.

Summary of Results taken from the experiments as follows:—

			Tons.		Elongation per unit of length.
Experiment I.,	Specimen	W	13·125	per sq. in.	·00950
„ II.,	„	W	11·714	„	·01500
„ III.,	„	BW	14·762	„	·01333
„ IV.,	„	B	15·189	„	·01131
Mean			13·697		·01229

Being nearly double the strength of ordinary cast-iron.

Similar results, although not to the same extent, are obtained in the following summary of experiments on compression. They also indicate greatly superior powers of resistance to a crushing force, and approximate closely to the inferior descriptions of wrought-iron as regards a tensile strain, and above that of cast-iron to compression.

Summary of Results.

			Crushing strength in tons.	Mean compression per unit of length.
Experiment V.,	Specimen	B	60·037	·084
„ VI.,	„	WB	59·237	·170
„ VII.,	„	W	52·837	·098
Mean			57·370	·117

From the above summary of experiments on tension, we derive these important facts—namely, that cast-iron may be increased in the strength of its molecular construction to an

extent considerably beyond that of ordinary cast-iron, and this may be done at a very moderate cost, by adopting the admixture of wrought-iron turnings, as first chosen by Mr. Stirling, or it may be accomplished on the principle adopted by Dr. Price, which gives still higher powers of resistance. It is therefore important that we should ascertain not only the best description of armour-plates calculated to resist projectiles of any description; but it is equally important that we should employ the most powerful description of shot to overcome that resistance.

Now, we have already determined the kinds of shot and shell best adapted for the penetration and perforation of iron plates; but as cast-iron, from its cheapness, facility of moulding, etc., can be produced at a comparatively small cost, it is desirable to ascertain in what manner and to what extent its tenacity can be increased, so as to approximate the strength of wrought-iron or homogenous metal.

The present state of our knowledge is limited in this respect, and a series of well-conducted chemical and mechanical experiments to determine these points would be highly valuable.

In the above experiments it has been shown that the cast-iron shot prepared by Dr. Price is of a high order, and that cast-iron may be toughened either upon the Stirling principle, by an admixture of wrought-iron, or by Dr. Price's method, which gives such good results. The object to be attained appears to be, that the shot should be sufficiently tenacious to resist the effects of impact, when it comes in contact with the plate; or, in other words, it should be able to deliver the whole of its *vis viva* upon the armour-plate without breaking. This cannot be expected from shot composed of this description of material, but it may be greatly increased in tenacity, and rendered much more destructive in its effects, than if made of ordinary cast-iron.

It is true that up to the present time common cast-iron shot was quite sufficient for the purposes of naval warfare, as in no case was the shot known to be broken in pieces when fired against wooden ships. It is, however, widely different against iron sides, and unless the shot is made equally tenacious with the plate by which its progress is arrested, only a part of its force is delivered upon the plate, the remainder of that force being expended or thrown back —if I may use the expression—upon itself, and shattered to pieces.

It is for these reasons that I would suggest a more extended inquiry into the condition of the material now employed in the manufacture of shot; and as there is at the present moment a wide field open for investigation, I think it would be unpardonable to allow the opportunity to escape, where so much has to be done, and where the interest of science and the security of the country are at stake.

I am not conversant with the process by which Dr. Price has arrived at the results detailed in the experiments on his cast-iron shot; but, judging from the appearance of the fracture, and from the minute character of the crystals, and density of the material, I am inclined to believe that it is of much higher specific gravity than that of ordinary cast-iron; and it is desirable that Dr. Price should continue his experiments, and endeavour still further to increase the density, tenacity, and other favourable conditions of cast-iron shot.

We have shown that cast-iron is greatly improved in strength by an admixture of wrought-iron, but we have not noticed what may yet be done by a judicious process of decarbonisation, where the metal is in a perfectly fluid state, and at a high temperature.

A process of this kind, either upon the Bessemer or some other equally effective system, would convert the metal into a species of steel at a comparatively small cost, with im-

mense advantage to its tenacity. In this preparatory state it might be cast, as in all fluid metals, into the shape and form required for ordnance of any description. For particular purposes, and for special service, hardened steel is the only material calculated for the perforation of armour-plates; but this material is expensive, as it has to undergo several expensive processes of hammering, heating, and rolling, before it is sufficiently consolidated to answer the purpose of powerfully-resisting shot that will not fracture by impact.

It is immaterial whether this metal is prepared in the puddling furnace, or the Bessemer kettle; to give it solidity it must be re-wrought and consolidated, either by compression or under the hammer, to attain the required density by a close adherence of its crystalline structure. These processes are necessary to make it sufficiently adherent to resist blows at the point of contact, and to deliver its entire force upon the plate without the risk of fracture.*

Power to Resist Torsion.

The following experiments were made by the American Government on the torsional strength of iron cast in various forms. The distance between the keys which secure the ends of the bar when strained was 15 inches. The length of that part of the bar subject to torsion was about 8 diameters. It appeared that the force requisite to give the bar a permanent set of ½° is about 9-10ths of that which will break it. With wrought-iron they found that with forces not producing a permanent set, its capacity to resist torsional deflection is equal to that of cast-iron. But set commences with a less

* See page 194 on the Bessemer process of manufacturing spherical steel shot.

strain in wrought than in cast iron, and the material yields more readily thereafter. The mean value of the strain giving a set of $\frac{1}{2}°$ in wrought-iron is about 6-10ths the mean value of the strain giving a like set to cast-iron. The resistance of bronze to torsion is much less than either, being about one-third that of cast-iron.

TABLE XVI.—*Mean Results on Torsion of Cast-iron.*

Description of Metal.	Fusion.	Diameter.	Angles of Permanent Set at					Breaking Weight.	Torsional Strength, $S=\frac{wr}{d^3}$		
			1000 lbs.	1500 lbs.	2000 lbs.	2500 lbs.	Maximum.		Ultimate.	At set of $\frac{1}{2}°$	Ratio.
No 1, cast iron	2d	1·916	0°·2	2°·2	...	...	12°·9	1737	6,176	4442	·724
	3d	1·875	0 ·0	0 ·3	3°·8	...	16 ·0	2320	8,799	6447	·733
Nos. 1 and 3, cast-iron .	2d & 3d	1·913	0 ·0	0 ·1	0 ·7	2°·4	10 ·5	2730	9,752	6611	·678
Nos. 1 and 2, cast-iron .	2d	1·927	0 ·1	0 ·9	...	...	21 ·7	2245	9,847	4723	·601
	3d	1·893	0 ·0	0 ·0	0 ·8	4 ·9	16 ·7	2840	10,467	7000	·669
Nos. 1, 2, and 3, cast-iron .	2d	1·908	0 ·0	0 ·1	1 ·0	3 ·9	14 ·0	2697	9,711	6793	·700
	3d	1·908	0 ·1	0 ·2	0 ·5	2 ·5	6 ·9	2515	9,065	7130	·786

MALLEABLE IRON.

The greatly extended application of wrought-iron to every variety of construction renders an investigation of its properties peculiarly interesting. It is now employed more extensively than cast-iron; on account of its ductility and strength, nearly two-thirds of the weight of material may in many cases be saved by its employment, while great lightness and durability are secured. Its superiority is especially evident in constructions where great stiffness is not required; but on the other hand any degree of rigidity may be obtained by the employment of a tubular or cellular structure, and this may be seen in the construction of wrought-iron tubular bridges, beams, and iron ships. Malleable iron, which is making such

vast changes in the forms of construction, cannot but be interesting and important; and considering that the present is far from the limit of its application, we shall endeavour to give it that degree of attention which the importance of the subject demands.

From the forge and the rolling-mill we derive two distinct qualities of iron, known as "*red short*" and "*cold short*." The former is the most ductile, and is a tough fibrous material, which exhibits considerable strength when cold; the latter is more brittle, and has a highly crystalline fracture, almost like cast-iron; but the fact is probably not generally known, that the brittle works as well, and is as ductile under the hammer as the other, when at a high temperature.

Mr. Charles Hood, in a paper read some time ago before the Institute of Civil Engineers, went into the subject of the change in the internal structure of iron independently of and subsequently to the processes of its manufacture. After adducing several instances of tough fibrous malleable iron becoming crystalline and brittle during their employment, he attributes these changes to the influence of percussion, heat, and magnetism, but questions whether either will produce the effect *per se*. Mr. Hood continues: "The most common exemplification of the effect of heat in crystallising fibrous iron is, by breaking a wrought-iron furnace bar, which, whatever quality it was of in the first instance, will in a short time invariably be converted into crystallised iron, and by heating and rapidly cooling, by quenching with water a few times any piece of wrought-iron, the same effect may be more speedily produced. In these cases we have at least two of the above causes in operation—heat and magnetism. In every instance of heating iron to a very high temperature, it undergoes a change in its electric or magnetic condition; for at very high temperatures iron loses its magnetic powers, which return as it gradually cools to a lower temperature. In the case of

quenching the iron with water, we have a still more decisive assistance from the electric and magnetic forces; for Sir Humphry Davy long since pointed out that all cases of vaporisation produced negative electricity in the bodies in contact with the vapour; a fact which has lately excited a good deal of attention in consequence of the discovery of large quantities of negative electricity in effluent steam."

Mr. Hood then proceeds to the subject of percussion: "In the manufacture of some descriptions of hammered iron, the bar is first rolled into shape, and then one-half the length of the bar is heated in a furnace, and immediately taken to the tilt-hammer and hammered, and the other end of the bar is then heated and hammered in the same manner. In order to avoid any unevenness in the bar, or any difference in its colour where the two distinct operations have terminated, the workman frequently gives the bar a few blows with the hammer upon that part which he first operated upon. That part of the bar immediately becomes crystallised, and so extremely brittle that it will break to pieces by merely throwing it on the ground, though all the rest of the bar will exhibit the best and toughest quality imaginable.

This change, therefore, has been produced by percussion (as the primary agent) when the bar is at a lower temperature than the welding heat. Here it must be observed that it is not the excess of hammering which produces the effect, but the absence of a sufficient degree of heat, at the time that the hammering takes place; and the evil may probably be all produced by four or five blows of the hammer if the bar happens to be of a small size. In this case we witness the combined effects of percussion, heat, and magnetism. When the bar is hammered at the proper temperature, no such crystallisation takes place, because the bar is insensible to magnetism; but as soon as the bar becomes of that lower degree of temperature at which it can be affected by mag-

netism, the effect of the blows it receives is to produce magnetic induction, and that magnetic induction, and consequent polarity of its particles, when assisted by further vibrations from additional percussion, produces a crystallised texture."

The crystallisation of perfectly fibrous and ductile wrought-iron has long been a subject of dispute; and although we agree with most of Mr. Hood's views, we are not altogether prepared to admit that the causes assigned are the only ones concerned in producing the change, or that more than one is *necessary*. On occasion of the accident on the Versailles Railway some years since, the whole array of science and practice was brought to bear upon the elucidation of the cause. Undoubtedly the broken axle presented a crystalline fracture, but it has never been ascertained how far heat and magnetism were in operation, as, in the case of an axle, and more especially a crank-axle, the constant vibration caused by irregularities in the way and the weight of the engine, appears to be quite sufficient to occasion the breakage without aid from the other forces. Undoubtedly, in almost all cases of the sudden fracture of axles or wrought-iron bars, during employment, the fracture presents a crystalline structure; but we believe that any molecular disturbance, such as impact, can effect this, by breaking the fibre into a number of prisms, each of which, carefully examined, has the appearance of a crystal, the only question being, how long will the material sustain the repeated effects of strain action before it breaks? This question has been attempted to be decided by direct experiment under the direction of the Commission on Railway Structures. It was found that with cast-iron bars subjected to long-continued impacts, "when the blow was powerful enough to bend the bars through one-half of their ultimate deflection (that is to say, the deflection which corresponds to their fracture by dead pressure), no bar was able to stand 4000 of such blows

in succession. But all bars (when sound) resisted the effects of 4000 blows, each bending them through one-third of their ultimate deflection. These results were confirmed by experiments with a revolving cam which deflected the bars.

"In wrought-iron bars, no very perceptible effect was produced by 10,000 successive deflections by means of a revolving cam, each deflection being due to half the weight which, when applied statically, produced a large permanent flexure." These results agree with those obtained by my own experiments in regard to the effects of time on loaded bars of cast-iron already given.

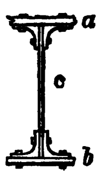
Arago and Wollaston have paid considerable attention to this subject, the latter having been the first to point out that native iron is disposed to break in octohedra and tetrahedra, or combinations of these forms. The law which leads to fracture in wrought-iron from changes in the molecular structure, operates with more or less intensity in other bodies; repeated disturbances in turn destroying the cohesive force of the material by which they are held together. A French writer of eminence, Arago, appears to consider the crystallisation of wrought-iron to be due to the joint action of time and vibration; but we think, with Mr. Hood, that time and its duration depend entirely upon the intensity of the disturbing forces, and, moreover, that the time of fracture is retarded or accelerated in a given ratio to the intensity with which these forces are applied.

From the above statements we may safely deduce the fact, that it is essential to the use of this material to consider the purposes to which it is applied, the forms in which it may be moulded, and the conditions under which it may be placed, in order to arrive at just conclusions as to the proportions, in order to afford to the structure (whatever that may be), ample security in its powers of resistance to strain.

The numerous accidents that have occurred from the

changes that have taken place in wrought-iron subjected to a long-continued series of repeated strains (passing from what is supposed to be the fibrous to the crystalline state), induced the Lords Commissioners for Trade to enlarge the margin of strength as respects wrought-iron bridges, and to insist that the strains should not exceed five tons on the square inch. This decision led to a request that I would investigate this important question; and having constructed a model beam, representing a girder of a bridge in actual existence, the following summary of results, deduced from the experiments, was obtained.

The beam or girder subjected to vibratory strains in these experiments was a wrought-iron plate beam, with angle irons and plates, top and bottom, as per annexed section—



The area of top flange, *a*, was	4·3 inches
Area of bottom flange, *b* .	2·4 „
Middle web, *c* . . .	1·9 „
Total sectional area .	8·6 inches.

Depth of beam	16 inches.
Weight	7 cwts. 3 qrs.
Calculated breaking weight . . .	12 tons.
And the distance between the supports .	20 feet.

With these data, 1,000,000 of changes of load were made with weights varying from $\frac{1}{4}$ to $\frac{2}{5}$ of the load that would break it. In the first series of experiments, which extended from the 26th of March to the 26th of July ensuing, the experiments were continuous till it broke; and the second series of experiments on the same beam, after being repaired, sustained 3,000,000 additional changes, with a reasonable load, as given in the following summary, when it broke :—

Summary of Results.—*First Series of Experiments.*

Beam 20 Feet between the Supports.

No. of Experiment.	Date.	Weight on Middle of the Beam in Tons.	Number of changes of Load.	Strain per sq. inch on Bottom.	Strain per sq. inch on Top.	Deflection in inches.	Remarks.
1	From March 21st to May 14th 1860	2·96	596,790	4·62	2·58	·17	
2	From May 14th to June 26th 1860	3·50	403,210	5·46	3·05	·23	
3	From July 25th to July 28th 1860	4·68	5,175	7·31	4·08	·35	Broke by tension a short distance from the centre of the beam.

Here it will be observed that the number of 1,005,172 changes was attained before fracture, with varying strains upon the bottom flange of 4·62, 5·46, and 7·31 tons per square inch; and in the

Second Series of Experiments—

Beam repaired—the following Results were obtained:—

No. of Experiment.	Date.	Weight on Middle of the Beam in Tons.	Number of Changes of Load.	Strain per sq. inch on Bottom.	Strain per sq. inch on Top.	Deflection in inches.	Remarks.
1	August 9th, 1860 . .	4·68	158	7·31	4·08	...	The apparatus was accidentally set in motion.
2	August 11th and 12th .	3·58	25,742	3·59	3·12	·22	
3	From August 13th, 1860, to October 16th, 1861	2·96	3,124,100	4·62	2·58	·18	
4	From October 18th, 1861, to January 9th, 1862 .	4·00	313,000	6·25	3·48	·20	Broke by tension as before close to the plate riveted over the previous fracture.

The number 3,463,000 changes was, in this case, attained before fracture ensued.

From the above it is evident that wrought-iron girders, when subjected to a load equal to a tensile strain of 7 tons per square inch, are not safe if that strain is subjected to alternate changes of taking off the load and laying it on again, provided a certain amount of vibration is produced by that process; and what is important to notice is, that from 300,000 to 400,000 changes of this description are sufficient to insure fracture. It must, however, be borne in mind, that the beam from which these conclusions are derived had sustained upwards of 3,000,000 changes, with nearly five tons tensile strain on the square inch; and it must be admitted, from the experiments thus recorded, that 5 tons per square inch of tensile strain on the bottom of girders, as fixed by their Lordships, is an ample standard of strength.

As regards compression, we have only to compare for practical purposes the difference between the resisting powers of the material to tension and compression, and we shall require in a girder without cellular top from one-third to three-fourths more material to resist compression than that of tension; and as wrought-iron, in a state of compression, is, to that of tension, as about 3 to 4·5, the area of the top and bottom will be nearly in that proportion, or in other words, it will require that much more material in the top than the bottom to equalize the two forces.

In the experimental beam, the area of the top was considerably in excess of that of the bottom, having been constructed on data deduced from the experiments on tubes without cells, which required nearly double the area on the top to resist crushing. In the construction of larger girders, where thicker plates are used, this proportion no longer exists, as much greater rigidity is obtained from the thicker plates, which causes a closer approximation to equal area, in the top and bottom of the girder; and from this we deduce that from $\frac{1}{2}$ to $\frac{3}{4}$, and in some cases $\frac{1}{3}$ additional area in the top has been

found, according to the size of the girder, sufficient to balance the two forces under strain.

The foregoing experiments were, however, instituted to determine the safe measure of strength as respects tension, and it will be seen that in no case during the whole of the experiments was there any appearance of the top yielding to compression.

In all these experiments it will be observed that we have taken the whole area of the bottom flange, without deducting for the rivet-holes in the angle irons and the bottom plate (and there being four of ½-inch diameter in the bottom flange, two in each angle iron, and two in the plate), which is equal to ·625 inches. This reduces the area for tension from 2·4 to 1·775 inches. In the calculations I have not, however, made these deductions, in order that the experiments might compare with others where they have not been taken into account. Under the conditions of reduced area, it will be found that the strains per square inch upon the bottom flange, with the variable load, according to the formula, will be as follows :—

	Weight on middle of beam in tons.	No. of changes.	Strain per square inch on bottom flange.
1st Experiment, May 14th, 1860 .	2·96	596,790	6·25
2d Experiment, June 26th, 1860 .	3·50	403,201	7·39
3d Experiment, July 28th, 1860 .	4·68	5,175	9·88
BEAM REPAIRED.			
1st Experiment, August 9th, 1860 .	4·68	158	9·88
2d Experiment, August 12th, 1860	3·58	25,742	7·56
3d Experiment, October 16th, 1861	2·96	3,124,100	6·25
4th Experiment, January 9th, 1862	4·00	313,000	8·45

From the above it will be seen that the actual strain upon the solid plate was considerably increased. And the beam broke in the first series with a strain of nearly 10 tons upon the square inch; and in the second with a strain of 8½ tons, after sustaining 3,463,000 changes of load. From this it may be inferred that a wrought-iron bridge would be perfectly safe

for a long series of years with a strain of 6 tons per square inch, or one-fourth the statical breaking weight. It is, however, evident from these experiments that time is an element which enters into the resisting powers of materials of every description when subjected to a continued series of changes. These may be very minute, but assuming them to be of sufficient force to produce molecular disturbance, it then follows that rupture must eventually ensue.*

Tensile Strength.

On the subject of the strength of wrought-iron there are my own researches, contained in a paper entitled, "An Inquiry into the Strength of Wrought-iron Plates and their Riveted Joints, as applied to Shipbuilding and vessels exposed to severe strain."† In that communication it is shown, from direct experiments, that in plates of rolled iron there is no material difference between those torn asunder in the direction of the fibre, and those torn asunder across the fibre. This uniformity of resistance arises probably from the way in which the plates are manufactured, which are generally out of flat bars, cut and piled upon each other, as at A (Fig. 71), one-half transversely, and the other half longitudinally in the line of the pile. From this it will be seen that, in preparing the bloom or shingle for the rollers, the fibre is equally divided, and the only superiority that can possibly be attained is in the rolling, which draws the shingle rather more in the direction of the length of the plate than in its breadth.

A

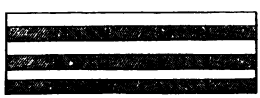


Fig. 71.

In the following table we have the results of the experiments :—

* See Philosophical Transactions for February 1864.

† Philosophical Transactions, part ii. 1850, p. 677. "Useful Information for Engineers," first series, Appendix 1.

TABLE XVII.—*Tensile Strength of Wrought-Iron Plates.*

Quality of Plates.	Mean Breaking Weight in the direction of the fibre, in tons per sq. inch.	Mean Breaking Weight across the fibre, in tons per square inch.
Yorkshire plates . .	25·770	27·490
Yorkshire plates . .	22·760	26·037
Derbyshire plates . .	21·680	18·650
Shropshire plates . .	22·826	22·000
Staffordshire plates .	19·563	21·010
Mean	22·519	23·037

Or as 22·5 : 23·0, equal to about $\frac{1}{45}$ in favour of those torn across the fibre.

From the above it is satisfactory to know, so far as regards uniformity in the strength of plates, that the liability to rupture is as great when drawn in one direction as in the other; and it is not improbable that the same properties would be exhibited, and the same resistance maintained, if the plates were drawn in any particular direction obliquely across the fibrous or laminated structure.

The following table contains a summary of the more recent experiments which I have made on the subject of the tensile strength of wrought-iron:—

TABLE XVIII.—*Tensile Strength of Wrought-Iron.*

Description of Iron.	Mean Breaking Weight in tons per square inch. With fibre.	Mean Breaking Weight in tons per square inch. Across fibre.	Ultimate elongation.
Lowmoor iron (sp. grav. 7·6885) . .	28·661	23·433	
Lancashire boiler plates (9 specimens)	21·815	20·096	$\frac{1}{23}$ and $\frac{1}{36}$
Staffordshire iron (Two ½-inch plates riveted together)	21·357		...
Charcoal bar-iron	28·402	...	$\frac{1}{5}$
Best-best Staffordshire charcoal plate (Mean of 4 experiments)	20·095	18·492	$\frac{1}{20}$ and $\frac{1}{22}$
Best-best Staffordshire plates (Mean of 4 experiments)	22·297	20·745	$\frac{1}{20}$ and $\frac{1}{26}$
Best-best Staffordshire plate	26·706	24·474	$\frac{1}{15}$ and $\frac{1}{25}$
Best Staffordshire	27·357	24·027	$\frac{1}{13}$ and $\frac{1}{22}$
Common Staffordshire	22·688	23·582	$\frac{1}{20}$ and $\frac{1}{23}$
Lowmoor rivet iron (Mean of 2 expers.)	26·801	...	$\frac{1}{4}$
Staffordshire rivet iron	26·563	...	$\frac{1}{4}$
Staffordshire rivet iron	26·646	...	$\frac{1}{5}$
Bar of the same rolled cold	37·956	...	$\frac{1}{12}$
Staffordshire bridge iron	21·249	19·815	$\frac{1}{25}$ and $\frac{1}{35}$
Yorkshire bridge iron	22·290	19·616	$\frac{1}{25}$ and $\frac{1}{28}$

In the above table, where two ultimate elongations are given, the first is that of the specimens broken with the strain in the direction of the fibre; the latter that of the specimens broken across the fibre. The mean ultimate elongation of Staffordshire bridge plates, from nine experiments by Mr. Edwin Clarke, was $\frac{1}{37}$; for rivet iron, bearing a strain of 24 tons before breaking, $\frac{1}{8}$. Here in the above table we have for Staffordshire bridge plates a mean of $\frac{1}{30}$, and for Yorkshire plates $\frac{1}{28}$. In the rivet iron there is little or no difference between the Staffordshire and the Yorkshire, both of them bearing $26\frac{1}{2}$ tons to the square inch, and $\frac{1}{4}$ of ultimate elongation.

From a previous inquiry we select the results of a series of experiments on the tensile strength of S C bars of different lengths, and about $1\frac{3}{8}$ inches in diameter. The following tables give the strains required for each of four successive breakages of the same pieces of iron. These experiments are highly interesting, as they not only confirm those made upon plates, but they indicate a progressive increase of strength, notwithstanding the elongation and the reduced sectional area of the bars. These facts are of considerable value, as they distinctly show that a severe tensile strain is not seriously injurious to the bearing powers of wrought-iron, even when carried to the extent of four times repeated, as was done in these experiments. In practice, it may not be prudent to test bars and chains to their utmost limit of resistance; it is nevertheless satisfactory to know that in cases of emergency those limits may be approached without incurring serious risk of injury to the ultimate strength of the material.

The following abstract gives the results of the experiments :—

General Abstract of Results.

Length between the nippers.	Breaking Strain in tons.	Mean elongation in inches.
Inches.		
120	32·21	26·0
42	32·125	9·8
36	32·35	8·8
24	32·00	6·2
10	32·29	4·2

"As all these experiments were made upon the same description of iron, it may be fairly inferred that the length of a bar does not in any way affect its strength."

Reduction of the above Table.

Length of Bar.	Elongation.	Elongation per unit of length.
Inches.		
120	26·0	·216
42	9·8	·233
36	8·8	·244
24	6·2	·258
10	4·2	·420

"Here it appears that the rate of elongation of bars of wrought-iron increases with the decrease of their length. Thus, while a bar of 120 inches had an elongation of ·216 inch per unit of its length, a bar of ten inches has an elongation of ·42 inch per unit of its length, or nearly double what it is in the former case. The relation between the length of a bar and its maximum elongation per unit may be approximately expressed by the following formula, viz.—

$$l = \cdot 18 + \frac{2\cdot 5}{L},$$

where L represents the length of the bar, and l the elongation per unit of the length of the bar."

The above results are not without value, as they exhibit the ductility of wrought-iron at a low temperature, as also the greatly-increased strength it exhibits with a reduced sectional area under severe strain.

The following results were obtained on the tensile strength of wrought-iron produced by the Bessemer process at the Royal Arsenal, Woolwich, under the superintendence of Colonel Eardley Wilmot :—

TABLE XIX.—*Tensile Strength of Mr. Bessemer's Iron in Pounds per Square Inch.*

In its cast unhammered state.		Hammered or rolled.	
Various trials.	Mean.	Various trials.	Mean.
lbs.		lbs.	
38,197		76,195	
41,584	41,242 lbs.	75,598	72,643 lbs.
43,290	=18·412 tons.	65,253	=32·430 tons.
40,234		64,095	
42,908		82,110	

Flat Ingot rolled into Boiler Plate.

Various trials.	Mean.
lbs.	
63,591	
73,103	= 68,319 lbs. = 30·50 tons
63,688	
72,896	

From the above will be observed the difference between the iron when compressed by the hammer or rolls and when taken in a state of ebullition from the converting furnace, while, although perfectly malleable, it is nevertheless in a crystalline state, the crystals probably requiring to be brought into more immediate contact by impact or compression, as exhibited by the simple process of elongation under the mechanical influence of welding under the hammer or rolls. These processes, as may be seen, add one-half to the strength of the iron, the difference being in the ratio of 18 : 32.

Mr. Clay gives the following interesting experiment on the effect of reheating and frequent rolling on the tenacity of wrought-iron. Taking a quantity of ordinary fibrous puddled

iron, and reserving samples marked No. 1, he piled a portion five feet high, and heated and rolled the remainder into two bars, marked No. 2. Again reserving two samples from the centre of these bars, the remainder were piled as before, and so continued until a portion of the iron had undergone twelve workings. The following table shows the tensile strain which each bore :—

No. 1.	Puddled bar . . .	43,904 lbs.
2.	Reheated	52,864 „
3.	„	59,585 „
4.	„	59,585 „
5.	„	57,344 „
6.	„	61,824 „
7.	„	59,585 „
8.	„	57,344 „
9.	„	57,344 „
10.	„	54,104 „
11.	„	51,968 „
12.	„	43,904 „

It will be seen from this that the quality of the metal improved np to the fifth reheating, and then decreased at the same rate.

The experiments are analogous to my own experiments on the process of remelting cast-iron. (See page 228.)

Rivets and Resistance to Shearing.—With rivets and bolts, which fit accurately the holes in which they are placed, the resistance to shearing varies exactly as the sectional area of the material in the place of rupture, and may be taken as 32,500 lbs. per square inch for cast-iron, and 50,000 lbs. per square inch wrought-iron (Rankine).

Wrought-iron plates are united by riveted joints, in which the strength depends upon this form of resistance. The various forms of joints are known as lap-joints, in which one plate is lapped over the other and the rivets passed through each ; butt-joints, in which the edges of the plates are made to abut against each other, and a covering strip,

about four inches wide, is placed over the joint, and riveted to each of the plates; and lastly, chain-riveted joints, employed for the bottom of bridges, where it is essential to reduce as little as possible the strength of the parts, and therefore a covering strip of great length is employed (Fig. 72), and the rivets are placed behind one another. The strength of the parts in riveted joints is reduced, in consequence of the parts punched out, in the proportion given in the following summary:—

Assuming for the strength of the plate . .	100
The strength of the double-riveted joint will be	68
And that of the single-riveted joint . .	46

Or for practice, allowing for the larger number of rivets in combination,* the strengths per square inch in lbs. may be taken as follow:—

The strength of the plate being . . .	58,000
The double-riveted joint would be . .	35,000
And the single-riveted joint . . .	28,000

The great deficiency in the strength of joints subjected to a tensile strain caused considerable difficulty in designing the Britannia and Conway Bridges; double, treble, and quadruple riveting was thought of, but one after another was abandoned on account of the rivet-holes weakening the plates; and I should almost have despaired of attaining the object in view, but for the system of longitudinal or chain riveting having occurred to me, after repeated trials of other modes and forms. Experiment, however, established the perfect security of this method, which is shown in Fig. 72, where two lines of plate are supposed to be employed breaking joint, the joint in the upper one being covered by a strip 2 feet 8 inches long, secured by thirty-two rivets placed in rows.

* The general rule for proportioning riveted joints is, that the shearing area through the rivets should be equal to the area of resistance in the plate after deducting the rivet-holes.

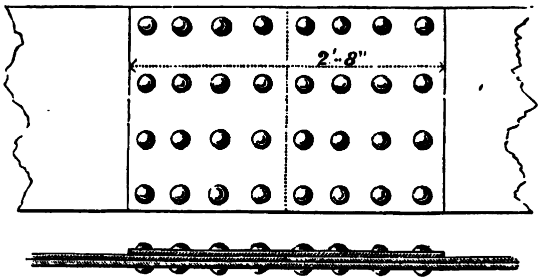


Fig. 72.

The following is the result of an experiment on a joint of this form:—

Area of section through plates 2 × ·875 = 1·75 square inch.
Area of section through rivet-holes 1·5 "
Rivets ½ inch diameter.
Broke with 69,664 lbs.
Equivalent to 17·77 tons per square inch.

Another experiment was made with a plate with two covering strips over the joint (Fig. 73).

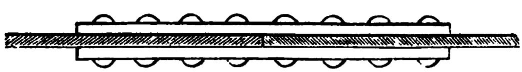


Fig. 73.

Area of section through solid plate, 3·5 × ·25 = ·875 square inch.
Area of section through rivet-holes, 3·0 × ·25 = ·750 " "
Diameter of rivets, ½ inch.
Broke with 41,002 lbs.
Equivalent to 20·92 tons per square inch, about the ultimate strength of the plate itself.

The defects of the riveted joint are so evident that various attempts have been made to reduce these evils. At the commencement of the trade in iron shipbuilding I patented an arrangement for rolling plates with thick edges, and employed plates so prepared to some extent; but the cost of their production at that time, and the difficulties which surrounded their employment, prevented their coming into general use.

Mr. Bertram has much more recently attempted to unite plates by welding, and with some success. The joints so made are far stronger than the ordinary riveted joint, but their cost at present prevents their introduction. Mr. Bertram scarfs the edges of the plates, places them together, and heats them by two pure gas flames ejected from nozzles, and produced by the ignition of coke or charcoal in a closed chamber by a regulated blast. Fig. 74 shows the way in which this is effected; but as yet we have no proofs of its ultimate success.

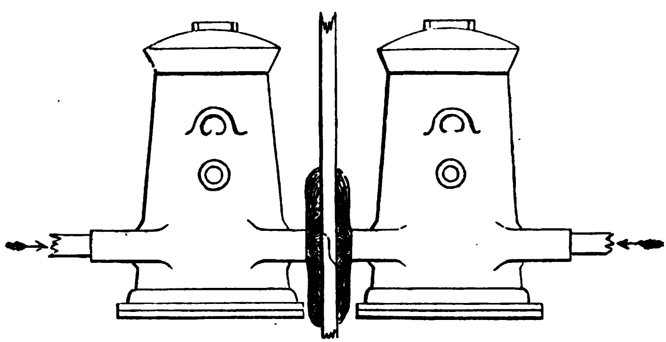


Fig. 74

Resistance to Buckling or Bending from a Compressive Force.

Professor E. Hodgkinson has experimented upon this subject, and his results show that the resistance of plates of the same breadth and length varies as the cube of the thickness, or more nearly as the 2·878 power of it. Thus, a plate double the thickness of another will resist flexure with seven or eight times the force applied in the direction of its length.

TABLE XX. *Resistance of Plates of Wrought-Iron to a Force of Compression, the plates being in a vertical position, and well bedded against parallel and horizontal crushing surfaces.*

Length of plates.		Dimensions of section.		Weight of greatest resistance.	Weight per sq. inch of section, of greatest resistance.	Value of power of thickness deduced.
ft.	in.	in.	in.	lbs.	tons.	
10	0	3·00 ×	1·51	46,050	4·538	2·622
		3·01 ×	·766	7,793	1·508	
10	0	3·00 ×	1·51	46,050	4·538	3·073
		2·99 ×	·995	12,735	1·911	
7	6	3·00 ×	1·53	91,746	8·923	2·898
		2·983 ×	·5023	3,614	1·076	
7	6	3·005 ×	·9955	29,619	4·425	3·064
		2·983 ×	·5023	3,614	1·076	
5	0	3·01 ×	·995	54,114	8·066	2·735
		2·98 ×	·507	8,469	2·502	
					Mean . .	2·878

From this it would also appear, by a reduction of the results, that square bars of wrought-iron, long enough to be bent without being crushed, vary in strength as the 3·59th power of their lateral dimensions, or as $d^{3·59}$, where $d =$ the side of the square, the length being constant.

On the transverse strength of wrought-iron it will not be necessary to enlarge, as we have numerous examples before us in the experiments undertaken to determine the strength and form of the Britannia and Conway Tubular Bridges.* In these experiments will be found an entirely new description of form and construction, which have emanated from them, and which have led to a new era in the history of bridges, and the application of wrought-iron to other purposes besides those in connection with buildings, and its greatly extended application to the useful arts. For further information on this

* See Mr. Fairbairn's work on the Conway and Britannia Tubular Bridges.

subject, we may refer the reader to my own* and Professor Hodgkinson's works, in both of which will be found sufficient data to establish the great superiority of malleable over cast iron, or any other material, steel probably excepted, either as regards strength or economy in its application.

On the resistance of wrought-iron plates to a force tending to burst them, Rondelet has shown that it requires a force of 70,000 lbs. per square inch to produce fracture. My own experiments proved that a wrought-iron plate of one quarter of an inch thick resisted a pressure from a ball 3 inches in diameter equal to that required to rupture a 3-inch oak plank. More recent experiments against armour-plates from shot at high velocities have increased our knowledge on this subject, as shown in Chapter XI.

* "On the Application of Cast and Wrought Iron to Building Purposes," and "Useful Information for Engineers."

CHAPTER XI.

ARMOUR-PLATES.

THE future destiny of nations seems to be involved in the consideration of iron, and its application to an entirely new system of construction in vessels of war, calculated to unite with equal facility the powers of attack and defence. To combine this force and power of resistance in one construction, is a desideratum not yet attained, but every effort is now being made by the Government of this and other maritime nations to approximate as nearly as possible in the construction of ships of war to that desirable object. It appears from what has already been done by the Government of this country, and the preparations now going forward in the French dockyards, as also from the trials and experiments made in America, that the war ships and fleets of the future will undergo a thorough change, not only in form, but also in the material used in their construction. Thirty years' experience in the appliance of iron to the building of our mercantile navy has shown the great superiority of that material for shipbuilding; and much greater progress in this direction would have been made in the Government dockyards, but for two reasons—namely, the strong prejudices engendered against iron in the first instance, and the dangers arising from the effects of shot on iron ships in the second.

As early as 1834-35 the Admiralty were urged to institute a series of experiments, to solve the difficulties which appeared to surround these opinions; but it required several years before their Lordships made up their minds as to what should be done. At last, through the influence of the late Admiral Sir

George Cockburn and others, the subject of iron ships was brought under consideration, and targets were ordered to be prepared at Woolwich for experiment with a 32-pounder smooth-bore gun at a range of only thirty yards. The result was condemnatory of the use of iron, and the Admiralty then fell back upon the old wooden walls, as the only class of vessels calculated for the purposes of war. This decision on the part of the Government retarded everything in the shape of progress, until the French Emperor, in 1855, gave a fresh impetus to the subject by the introduction of thick iron plates for casing the sides of vessels, as a medium of resistance to projectiles at high velocities. This innovation—or invasion as it is now called—upon old constructions roused the lethargy into which we had fallen, and showed the weakness of our fleets and squadrons when exposed to the attacks of "iron-clads" of superior force, thoroughly protected by defensive armour. These facts, so strikingly exemplified by the French iron-cased batteries during the Crimean war, could no longer be resisted, and hence followed the changes and experiments which are now in progress. It would be premature to conjecture what may be the ultimate results of those changes, as fortunately we are not engaged in war to enable us practically to test the efficiency of the vessels already built on the new principle; nor have we sufficient experience to enable the Admiralty to determine what size, form, and class of vessels are best adapted for a particular service. We are, however, feeling our way by experiment in the right direction, and we may safely predict a new and successful era in the construction of iron vessels calculated to meet all the requirements of a powerful and effective navy.

Dr. Percy, in his laborious and excellent work "Metallurgy of Iron and Steel," published in 1864, states "that the term armour-plates is now generally applied to massive wrought-iron plates, with which ships of war are coated exter-

nally, where they are accessible to shot or shells; and since the adoption of this means of defence great and rapid progress has been made in the manufacture of these plates. Experiments have been conducted by the Governments of this country, of France, of Prussia, of Austria, and of Italy, with a view to ascertain the best quality of iron for the purpose, and the best mode of manufacture. Information of the highest value has thus been acquired," yet the subject is far from being exhausted at present.

"With regard to quality, it seems to have been decided that the iron should be as tough and soft as possible; and that steel, properly so designated, should especially be avoided. It might have been supposed that certain kinds of steel which possess far greater tensile strength than any kinds of wrought-iron would have been most suitable; but experiments have established the contrary. In determining tensile strength, the force employed to effect rupture is *slowly* applied; and results are obtained in this manner which may cease to be applicable in cases where impact takes place at such high velocities as 1200 feet and 1600 feet per second. In an early part of the present volume the subject of fracture under this latter condition was considered.

"It is a question, whether hammering or rolling, or a combination of both, will yield the best results; and each of these three methods of manufacture has its advocates, though perhaps the majority of persons have declared in favour of rolling. The fact is, that equally good plates have been produced by each method, when the manipulations have been conducted with proper skill. No large armour-plates are now made less than 4½ inches in thickness, as thinner plates would be immediately destroyed by the powerful artillery of recent times, and the resistance of superimposed plates, however firmly fastened together, is greatly inferior to solid plates of the same aggregate thickness."

In addition to these remarks by my friend and colleague Dr. Percy, I may state that the results taken from experiments and given in this chapter fully confirm the opinion thus recorded—namely, that the toughest and softest description of iron, when combined with careful manipulation in the manufacture, is essential to the production of a powerfully-resisting armour-plate.

This manufacture has to a great extent been accomplished by Messrs. Beale and Co. of the Park Gate Ironworks, Yorkshire, and Messrs. John Brown and Co. of Sheffield. Both of these firms have entered largely upon this important and difficult branch of manufacture, with—as Dr. Percy observes—a spirit of enterprise and persevering energy which does honour to the British nation.

Messrs. Beale and Co. were the first to erect rolling-mills on a large scale for this purpose, and Messrs. John Brown and Co. shortly followed with rolls of colossal dimensions, constructed for the exclusive purpose of rolling plates of 8 to 10 inches thick, and weighing, in some cases, upwards of 10 tons. These works were inaugurated with considerable *eclat*, on 9th April 1863, by the Lords of the Admiralty and others interested in mechanical progress.

The following extract from the *Times*' correspondent so graphically describes the operations of this gigantic machinery that it will be read with interest :—"Great furnaces, blaring in the fierce white glare which shone from their crevices, were stuffed to the mouth with monstrous cranks and shafts and uncouth bosses of red-hot metal. Every now and then some one of them was opened, with a flash that filled the smoky atmosphere with a glare as from snow, and a mass of metal, seething and spluttering in a blaze of sparks, was dragged off and moulded, like so much wax, under the blows of steam-hammers that made the earth tremble and the whole building to jump and chatter under the stroke, as if from the shock of

a little earthquake. It was wonderful to see the skill with which the groups of workmen, uniting all their individual exertions in a series of violent efforts, like a weird species of dance, contrived to hedge and move about the great masses on the anvils, so that the hammer struck only where and how they chose. While the heat lasted in the mass—and that was for a long time—they never paused or slackened in their work, and though literally almost scorched by their proximity to red heaps, they kept on toiling till the work was done, and the lump that a quarter of an hour before was almost melted iron was picked up by some huge crane that came travelling along the smoky walls, and carried off glowing through the gloom, a finished piece of work. At other places there were tilt and lever hammers, wearying the very air with the clattering din of their tremendous strokes. At others great ingots of steel were cast by the Bessemer process; small plates were rolled and roughly cast aside in great red slabs to cool, or hurried backwards and forwards in iron trucks, scorching even the hardened workmen out of their tracks as they came burning past. On every side there were furnaces and smoke and red-hot metals, while in out-of-the-way nooks men in steel caps and wire vizors, and cased below in rough steel leggings, like jackboots of iron, fought in a crowd, like so many salamanders, round some rough mass that was dangerous in its fierce heat, and which sent back aggressive spurts of red-hot metal in return for every blow. Such fiery combats as these were going on in all directions; the 'Sheffield carpet' of the factory—iron plates—was hot and painful to the feet; the air was arid with a sulphury warmth that was like the glow of an over-heated stove. When we have said thus much, and added that there were roaring pipes of steam mounting into the air, side by side with great iron trumpet-shaped chimneys, out of which jets of red flame roared and flapped into the smoke above like gigantic flambeaux; that lower down long lines of lathe-bands

flew noiselessly in all directions, and that the background was filled in with glimpses of ponderous fly-wheels whirling their arms through the smoke and turning rolling-mills or lapping-hammers, or shearing down with noiseless might the great lumps of iron that were brought in to be cut up ;—we have said enough to indicate the view which met visitors on their first introduction to this glowing scene of industry.

"Though not the first, yet by far the most important process which their Lordships were shown was the operation of rolling the great plate, by far the largest single plate that has ever yet been rolled in the world. This took place in what was called the New Mills of the Atlas Works, which were used on Thursday for the first time, and where great ranges of furnaces have been erected, with their mouths opening on the iron tramway which leads direct to the double rollers through which the plate passes. One may guess at the solidity required for mills of this kind when it is stated that some of the rolls used at this mill on Thursday have a first foundation of no less than 60 tons of solid iron, resting on masonry carried far below the earth. The rolls themselves are 32 inches in diameter and 8 feet wide, and are turned by an engine of 400 horse-power, putting in motion a fly-wheel large enough apparently to make a world rotate if only well balanced on its axis. A powerful screw, applying its force through compound levers, allows the distance between the rollers to be adjusted to the fraction of an inch, so that the plate which on its first rolling is forced through an interval of, for instance, 12 inches apart, is on its next, wound through one of 10, next through one of 8 ; and so on till the required thickness has been carefully and equally attained by tremendous compression through every part of the metal. There were a great many visitors to see the rolling of this formidable mass, which was fortunate, as one would certainly be frightened to witness the terrible process alone. After some delay, and quick glimpses made by the most

hardened workmen, who, rushing up to the door of the furnace, got a half-blinded glance into its white interior, it was decided that the mass was ready, for, strange as it may seem, an armour-plate requires more than mere heating, and has to be cooked, and watched in its cooking, with as much care as if it was an omelette, and the plate that is drawn before it is 'done to a turn' generally remains a permanent ornament of the unlucky manufacturer's workshop, which no one will have at any price. When at last this eventful moment had arrived on Thursday, the door of the furnace was slowly raised, and a colossal pair of pincers with very long handles, fastened to a chain drawn by machinery, was swung in. For an instant some men rushed forward, and, shielding their faces from the deadly heat that shot from the furnace, adjusted the bite of these forceps on the plate, and then ran back as the chain began to tauten, and the great inmate of the blazing den was slowly dragged forth on the long iron trucks in front of the door, and there lay in its huge length and thickness a mass of living fire, which none could approach or scarcely even look at, so fierce was its glow and terrific heat. The chains which should have pulled it forthwith to the rollers were too slack, and then arose shouts and cries and commands, as the men did battle with this mass of fire, coming so near it, in their attempts to gather up the slackened chains, that one literally almost expected to see them fall, scorched and shrivelled, on the ground. In its great glare they fought and struggled with the chains till at last all was adjusted, and the great pile of angry fire began to move slowly downwards towards the mills, the men following it with hoarse shouts and directions, now hid in steam, as buckets of water were dashed over the mass, and the next moment standing in an atmosphere of white light, to which the light of the day around was mere dusk. The rollers did not bite directly the mass came to them, and when they did the engine was almost brought to a standstill

by the tremendous strain upon it; but at last the soft plate yielded, and the rollers seemed to swallow it as they wound it slowly in, squeezing out jets of melted iron like squirts of fire, that shot about dangerously as the pile was compressed from 19 inches to 17 inches thick by the irresistible force of the rollers. *Ce n' est que le premier pas qui coûte,* and the victory was certain when the mass had once passed through the mill, and both visitors and workmen gave a tremendous cheer at the success. From this time it was kept rolling backwards and forwards, the workmen sweeping from its face the scales of oxide that gathered fast upon it with long-handled besoms that, though soaked in water, caught fire and blazed up as fast as they were used. With every time it was passed through, the rollers were screwed closer and closer together, as we have already mentioned, till, at the end of about a quarter of an hour after leaving the furnace an almost melted mass, it was passed through for the last time, and came out opposite the furnace-door it had so lately left, no longer shooting forth spiteful sparks, but shorn of half its heat, subdued and moulded to its proper form—a finished armour-plate, weighing 20 tons, 19 feet long, nearly 4 feet wide, and exactly 12 inches thick throughout from end to end. This is the most signal triumph that any rolling-mills have yet achieved.

"Other smaller plates were then rolled with a quickness and certainty that proved the skill already gained in this new and most important branch of manufacture. One plate was 17 feet long by 4 feet broad and 5½ inches thick; one 19 feet long by 4½ feet wide and 4½ inches thick; one we have already alluded to, 41 feet long by 3 feet 10 inches broad and 4½ inches thick. A lesser plate was also rolled 18 feet long, 5 feet wide, with a thickness of 6 inches on one edge and 3 inches on the other. The method of converting cast-iron by the Bessemer process into the tough soft Bessemer metal, a combination of the qualities between soft steel and tough

wrought-iron, was next shown. It is needless now to enter on a description of the very beautiful and very terrible process, to witness, which the metal goes through in the converter as it is stimulated to a white heat by the passage of the air blown by force-pumps upwards through the mass. No fire-works can surpass the brilliancy of the display this process affords as it approaches its completion, and the stream of violet flame and clouds of burning sparks pour from the mouth of the converter as from a gigantic squib. Nor is it necessary here to enter into a detail of the now well-known process, which was a subject of such controversy a few years since, but which is now being so generally and advantageously adopted throughout England and the continent. Suffice it to say, that in twenty minutes from the time of putting in the charge of cast-iron it was, without any expenditure of labour, poured out into the mould, an ingot of soft tough steel weighing three tons. This metal, after undergoing hammering, is now most extensively used for steel rails at stations, points, and junctions, where the wear is great, and in these trying situations it seems almost indestructible. A great deal has also been used in making Blakely rifled guns in this country for both Federals and Confederates. "These are the ordnance which the Americans always speak of as Parrott guns, and by them they are more highly prized than those of either Armstrong or Whitworth." O Sancta Simplicitas!!! Yet it is stated that the Ordnance Select Committee have refused even to try these guns at Shoeburyness. After these processes were over, and the various planing and filing shops had been duly examined, the visitors were entertained by Mr. Brown at a most sumptuous *déjeûner*."

During the years 1861-3 I have had frequent opportunities of recording the results of continually-augmented statical pressures on different qualities of iron, and comparing them with the effect produced by ordnance at Shoeburyness.

The following condensed summaries of results will give

considerable insight into the qualities and properties of the irons experimented upon :—

TABLE XXI.

Tension.

Description of plates.	Density.	Mean tenacity in iron.	Mean ultimate elongation per unit of length.	Foot pounds of work causing rupture.	Remarks.
A Plates	7·8083	24·644	·2723	7544·2	
B Plates	7·7035	23·354	·2459	6475·5	
C Plates	7·9042	27·032	·2725	8265·3	
D Plates	7·6322	24·171	·1913	5185·9	

The fracture of the iron plates in all the trials was of the dull grey laminated structure, except in the case of D, 3 inches thick, and B, 3 inches thick. These were more or less crystalline, but they were of average tenacity and more than average ductility, so far as that is indicated by the ultimate elongation. The homogeneous metal plates had a much brighter and closer texture, which might be described as finely granular in the 3-inch plate, and coarsely granular in the 2½-inch plate. The others were finely laminated.

With regard to the ultimate elongations given in the above table, the following additional remarks may be made :—Comparing the elongations of plates of the same make, we find the steel gives the greatest elongation, namely 0·2725 per unit of length in the thicker plates. But the A plates of iron are almost identical, namely 0·2723 ; and the B plates 0·2459 ; and lastly, very much lower, the D plates indicate 0·1913. In the steel plates the maximum elongation is given by the 2-inch plates ; in series A by the 3-inch plates ; in series B by the 2½-inch plates, and in series D by the 3-inch plates. That the iron plates give an elongation which increases with the thickness of the plates will be evident from the following numbers, which are the means of the elongations of the three series of iron plates :—

Thickness of plates in inches.	Mean ultimate elongation of plates A, B, and D, per unit of length.	Differences.
$\frac{1}{4}$	0·0333	
$\frac{1}{2}$	0·0427	0·0094
$\frac{3}{4}$	0·0700	0·0273
$1\frac{1}{2}$	0·1717	0·1017
2	0·2428	0·0711
$2\frac{1}{2}$	0·2560	0·0132
3	0·2728	0·0168

The relative amount of ultimate elongations in the thicker plates, taking the Lowmoor plates of series A as a standard, is—

A plates, iron . .	1·000
B plates, „	0·902
D plates, „	0·702
C plates, steel . . .	1·000

In these researches it will be observed that, assuming the amount of elongations to be the measure of ductility, the A plates from Lowmoor, and the C steel plates are, in the average, identically the same as regards softness of the material. But in the 3-inch plates the iron is very superior to the steel.

To ascertain the resistance to crushing, cylinders were prepared three-quarters of an inch in diameter and one inch in height. These were placed between parallel steel crushing surfaces, and subjected to pressure gradually increased to over 40 tons, or 90·9 tons per square inch of the original area.

All the specimens gradually squeezed down to about one-half their original height, increasing at the same time in diameter; but no pressure was reached at which the resisting powers of the material were entirely destroyed. The reason of this was, no doubt, that the increase of area supporting the pressure increased *pari passu* with the augmentation of the pressure itself.

The following is the summary of results :—

TABLE XXII.

No. of Expt.	Mark on Specimen.	Approximate thickness of plates.	Ultimate pressure per square inch		Ultimate compression per unit of length.	Ultimate permanent set per unit of length.	Remarks.
			Of original area.	Of increased area.			
			tons.	tons.			
1	A	$1\frac{1}{2}$	90·967	57·286	·509	·509	
2	A	2	90·967	53·487	·513	·513	
3	A	$2\frac{1}{2}$	90·967	52·946	·530	·530	
4	A	3	90·967	55·741	·516	·511	
5	B	$1\frac{1}{2}$	90·967	51·366	·537	·529	
6	B	2	90·967	53·268	·515	·510	
7	B	$2\frac{1}{2}$	90·967	54·596	·512	·506	
8	B	3	90·967	50·344	·539	·533	
9	C	$1\frac{1}{2}$	90·967	54·372	·499	·499	
10	C	2	90·967	54·937	·506	·501	
11	C	$2\frac{1}{2}$	90·967	57·895	·492	·485	
12	C	3	90·967	55·511	·503	·490	
13	D	$1\frac{1}{2}$	90·967	52·659	·509	·503	
14	D	2	90·967	53·217	·539	·532	
15	D	$2\frac{1}{2}$	90·967	50·154	·534	·522	
16	D	3	74·667	49·820	·498	·475	

In none of the above experiments was the specimen actually crushed. In every case it still bore the weight; but was reduced to at least half its previous height, was bulged out all round, and in most cases considerably cracked.

The plates of series C maintain the superiority indicated in the experiments on tension, squeezing down with great regularity and without cracking. Those of series B and series A were more or less cracked, except the two-inch B plate. The D plates were still more distorted and cracked.

The mean ultimate permanent sets were in the several series of plates as follows:—

A plates . .	·5158	mean set	1·000 ratio
B plates . .	·5195	„	1·007 „
C plates . .	·4988	„	0·967 „
D plates . .	·5080	„	0·984 „

The differences here are very small, showing, so far as they go, that the A and B series were softest, and that the C series exhibited the greatest resistance.

From the experiments on punching, we derive the resistance of A, B, C, D plates to a flat-ended instrument forced through the plate by dead pressure, as follows :—

TABLE XXIII.

Diameter of punch.	Approximate thickness of plate.	Shearing strain in tons per square inch.				Means of plates of the same thickness.
		A plates.	B plates.	C plates.	D plates.	
0·85 ins.	0·25	19·796	12·922	21·133	12·692	16·636
	0·50	19·378	19·034	23·750	16·410	19·643
	0·75	...	20·202	...	19·675	
0·50 ins.	0·50	19·359	18·215	27·403	17·858	20·709
	0·75	...	17·850	18·530	18·286	
	1·00	...	18·088	...	17·290	
Mean	...	19·511	17·719	22·704	17·035	

In these results we find the same order of merit as in most previous experiments. The relative resistance of each series, compared with the results on series A, being as follows :—

A plates . . .	1·000
B plates . . .	0·907
C plates . . .	1·168
D plates .	0·873

Here may be noticed, that the difference between the steel plates of series C and the iron plates of series A is not considerable, though in all the others the steel plates exhibit a superiority in statical resistance.

Having ascertained, by direct experiment, the mechanical resistance of different kinds of iron and steel plates to forces tending to rupture, it is interesting to observe the close relation which exists between not only the chemical analysis as obtained by Dr. Percy, but how nearly they approximate to

the force of impact, as exhibited in the experiments with ordnance at Shoeburyness.

Dr. Percy, in his analysis, observes, that of all the plates tested at Shoeburyness, none have been found to resist better than those lettered A, B, C, D, with the exception of C. The iron of plate E contained less phosphorus than either of the three, A, B, D; and it is clearly established that phosphorus is an impurity which tends in a remarkable degree to render the metal "cold short," *i.e.* brittle when cold.

The following table shows the chemical composition of these irons:—

TABLE XXIV.

Mark.	Carbon.	Sulphur.	Phosphorus.	Silicon.	Manganese.
A	0·01636	0·104	0·106	0·122	0·28
B	0·03272	0·121	0·173	0·160	0·029
C	0·230	0·190	0·020	0·014	0·110
D	0·0436	0·118	0·228	0·174	0·250
E	0·170	0·0577	0·0894	0·110	0·330

Comparing the chemical analysis with the mechanical properties of the irons experimented upon, we find that the presence of 0·23 per cent of carbon causes brittleness in the iron; and this was found to be the case in the homogeneous iron plates marked C; and although it was found equal to A plates in its resistance to tension and compression, it was very inferior to the others in resisting concussion or the force of impact. It therefore follows that toughness combined with tenacity is the description of iron plate best adapted to resist shot at high velocities. It is also found that wrought-iron, which exhibits a fibrous fracture when broken by bending, presents a widely different aspect when suddenly snapped asunder by vibration, or by a sharp blow from a shot. In the former case the fibre is elongated by bending, and becomes developed in the shape of threads as fine as silk; whilst in the

latter the fibres are broken short, and exhibit a decidedly crystalline fracture. But, in fact, every description of iron is crystalline in the first instance; and these crystals, by every succeeding process of hammering, rolling, etc., become elongated, and resolve themselves into fibres. There is therefore a wide difference in the appearance of the fracture of iron when broken by tearing and bending and when broken by impact, where time is not an element in the force producing rupture.

If we examine with ordinary care the state of our iron manufacture as it existed half a century ago, we shall find that our knowledge of its properties was of a very crude and most imperfect character. We have yet much to learn, but the necessities arising out of our position as a maritime people, and the changes by which we are surrounded, will stimulate our exertions to the acquisition of knowledge and the application of science to a more extended investigation of a material destined, in the course of time, to become the bulwark of the nation. It is therefore of primary importance that we should make ourselves thoroughly acquainted, not only with the mechanical and chemical properties of iron, but we should, moreover be able to apply it in such forms and conditions as are best calculated to meet the requirements of the age in which we live.

Entertaining these views, I cheerfully commenced with my talented colleagues the laborious investigations in which we were so recently engaged; and looking at the results of an experiment with the 300-pounder gun on the one hand, and the resisting targets on the other, there appeared every prospect of an arduous and long-continued contest.

From the Manchester experiments, to which I have alluded, we find, that with plates of different thicknesses the resistance varies directly as the thickness; that is, if the thickness be as the numbers 1, 2, 3, etc., the resistance will be as

1, 2, 3, etc.; but those obtained by impact at Shoeburyness show, that up to a certain thickness of plate, the resistance to projectiles increases nearly as the square of the thickness. That is, if the thickness be as the numbers 1, 2, 3, 4, etc., the resistance will be as the numbers 1, 4, 9, 16, etc., respectively. The measure, therefore, of the absolute destructive power of shot is its *vis viva*, not its momentum, as has been sometimes supposed; but the work accumulated in it varies directly as the weight of the shot multiplied into the square of the velocity.

There is therefore a great difference between statical pressure and dynamical effect; and in order to ascertain the difference between flat-ended and round-ended shot, a series of experiments were undertaken with an instrument or punch exactly similar in size and diameter, and precisely corresponding with, the steel shot of the wall-piece ·85 inches diameter employed in the experiments at Shoeburyness. The results on the A, B, C, and D plates are as follows:—

TABLE XXV.

Description of Plates.		Resistance in lbs.	
		Punch Flat-ended.	Punch Round-ended.
Half-inch thick .	A Plates . .	57,956	61,886
	B Plates . .	57,060	48,788
	C Plates . .	71,035	85,524
	D Plates . .	49,080	43,337
Three-quarter-inch thick	B Plates . .	84,587	98,420
	D Plates . .	82,381	98,571
	Mean . . .	67,017	72,754

These figures show that the statical resistance to punching is about the same whether the punch be flat-ended or round-ended, the mean being in the ratio of 1000 : 1085, or 8½ per cent greater in the round-ended punch. It is, however, widely different, when we consider the depth of indentation of the

flat-ended punch when compared with that produced by the round-ended one, which is $3\frac{1}{2}$ times greater. Hence, we derive this remarkable deduction, that whilst the statical resistance of plates to punching is nearly the same, whatever may be the form of the punch, yet the dynamic resistance or work done in punching is twice as great with a round-ended punch as with a flat-ended one. This of course only approximately expresses the true law; but it exhibits a remarkable coincidence with the results obtained by ordnance at Shoeburyness, and explains the difference which has been observed in these experiments, more particularly in those instances where round shot was discharged from smooth-bored guns at high velocities. To show more clearly the dynamic effect or work done by the weight of shot which struck some of the targets at different velocities the following results have been obtained :—

TABLE XXVI.

TARGET.	Weight of shot striking target; lbs.	Work done on Target.	
		Per square foot. Foot lbs.	Total foot lbs.
Thorneycroft 8-inch shield .	1253	242,316	29,078,000
Thorneycroft 10-inch embrasure	1511	492,933	37,140,000
Roberts's target	946	822,000	19,726,000
Fairbairn's target	1024	324,000	23,311,000
Warrior target	3229	312,000	62,570,000
The Committee's target . .	6410		124,098,780

From the above it will be observed that the two last targets have sustained in work done what would, if concentrated, be sufficient to sink the largest vessel in the British navy.

STEEL.

The properties of steel have been much less perfectly investigated than those of wrought-iron. The following table shows its tensile strength :—

	lbs. per sq. inch.	
Uchatius' cast-steel . . .	90,000	
Ordinary cast-steel . . .	128,000	
Krupp's steel gun . . .	129,000	
Mersey puddled steel . . .	94,752	(Mallet.)
Sheffield cast-steel . . .	130,000	(Rennie.)

The following table gives the results of some experiments under the direction of Colonel Wilmot at Woolwich on Mr. Bessemer's steel:—

TABLE XXVII.—*Tensile Strength of Mr. Bessemer's Steel.*

Tensile Strength per Square Inch of Section.			
In its cast, unhammered state.		Hammered or rolled state.	
Various trials.	Mean.	Various trials.	Mean.
48,892 lbs.	45,836 lbs.	162,974 lbs.	154,825 lbs.
42,780		146,676	
57,295	68,259	158,899	1 7,881
79,233		156,862	
72,503	68,998	136,490	148,324
77,808		145,512	
61,667		162,970	
64,015			

These results give a mean of 27·246 tons for the unhammered, and 68·607 for the hammered or rolled steel, per square inch of section. Hence the same anomalous condition exists in the steel as was noticed in the Bessemer iron, where the effects of the hammer or rolls produced nearly double the strength. In the steel we have in the first experiment more than three times the strength, and in the mean of the whole as 61 : 154—more than double. This evidently shows how very important it is to have the material, whether of iron or steel, elongated and solidified under the hammer, or between the rolls, before it is used.

In the following table are collected the results obtained by

myself on various descriptions of puddled steel and the so-called homogeneous metal:—

TABLE XXVIII.—*Experiments on the Tensile Strength of Steel.*

Description of Material.	Breaking weight in tons per sq. in.	Ultimate elongation per unit of length.
Homogeneous rolled steel (sp. gr. 7·8379)	41·510	
Rolled steel plate (hard) . . .		$\frac{1}{32}$
" " " (soft) . . .	38·129	$\frac{1}{32}$
Steel bar, puddled	40·196	
Steel plates, puddled, from Chesterfield (sp. gr. 7·8328)		$\frac{1}{8}$
Mr. Mushet's gun-metal . . .	46·176	$\frac{1}{29}$

The above are very fair specimens of the manufacture by different makers, and give a nearly uniform result. They are, however, greatly inferior, as regards strength, to the results obtained from the Bessemer steel by Colonel Wilmot, which gave upwards of 68 tons per square inch.

Latterly, I have tested specimens of bars of homogeneous steel from Messrs. Firth and Sons, in order more especially to ascertain their resistance to a transverse strain. They exhibited great ductility as well as tenacity; and were very uniform in their molecular construction. This characteristic, which was the distinguishing feature of these specimens, is a desideratum which, if preserved in the manufacture of plates, will be of great value in the industrial arts.

The following are the summaries of results:—

Tension.

	Breaking strain in tons.	Ultimate elongation per unit of length.
No. I. specimen . .	42·035 . .	·2450
II. " . .	41·428 . .	·2783
III. " . .	41·883 . .	·2450
IV. " . .	41·428 . .	·2316
Mean .	41·693	·2499

Transverse Strain.

Bars 1 inch square, and 4 feet 6 inches between supports.

	Weight laid on in lbs.	Deflection in inches.
No. I. specimen	984	9·860
II. "	928	9·670
III. "	984	11·120
IV. "	928	11·470
Mean	956	10·530

With additional weights these bars were rendered useless.

Compression.

To ascertain the resistance to crushing, cylinders were cut from the specimens 0·75 inches diameter and 1 inch high, which gave the following results :—

Area of Cylinders ·4417 *square inches.*

	Weight laid on in tons.	Weight per square inch of original area in tons.	Compression per unit of length.
No. I. specimen	42·0375	95·174	·433
II. "	42·0375	95·174	·427
III. "	42·0375	95·174	·401
IV. "	42·0375	95·174	·416
Mean	42·0375	95·174	·419

The foregoing results are very satisfactory, and exemplify a degree of uniformity in the manufacture very rarely attained.

CHAPTER XII.

THE CHEMICAL COMPOSITION OF IRON AND STEEL.

CAST-IRON is a carburet of the metal, of varying constitution, containing from 5 to 5·6 per cent of carbon. It, for the most part, exhibits a granular or laminar structure, and sometimes crystallizes in octohedra. Its fluidity and tenacity are considerably influenced by the per-centage of carbon which it contains, and the more so as the carbon exists in cast-iron in two conditions—viz., combined with the iron, or merely mechanically mixed with its crystals. Remelting the iron in the cupola increases its tenacity, reduces the quantity of graphite or mechanically-mixed carbon, and increases the proportion of combined carbon. In white cast-iron the whole of the carbon is combined. The grey varieties contain more manganese and silicium than the white.

The following results were obtained by Mr. Abel, of the Royal Arsenal, and communicated to the Chemical Society:—

Composition of Pig-Iron smelted with Charcoal.

	Nova Scotia.			America.		
	Gray.	Mottled.	White.	Gray.	Mottled.	White.
Specific gravity	7·120	7·540	7·690	7·159	7·540	7·675
Iron	95·20	95·35	95·25	94·87	96·35	96·55
Combined carbon	...	1·72	2·96	·04	1·14	2·79
Graphite	3·11	1·38	...	3·07	1·50	...
Silicium	1·11	·26	·21	1·80	·79	·32
Sulphur	·01	·03	·02	trace.	·01	·06
Phosphorus	·13	1·30	1·53	·22	·20	·17
Manganese	·25	trace.	...	trace.	trace.	trace.
Copper	...	...	...	trace.	trace.	trace.
	Traces of titanium and cobalt.					

At the request of the British Association, Dr. Thomson of Glasgow examined the chemical constitution of hot-blast iron, and he gave the following as the result of his inquiry :—

"(1.) The specific gravity of hot-blast iron is greater than that of cold-blast.

"The following are the specific gravities of eight specimens of cold-blast iron :—

1st, Muirkirk . . .	6·410	5th, Muirkirk . .	6·7754
2d, Ditto	6·435	6th, From pyrites .	6·9440
3d, Ditto	6·493	7th, From Carron .	6·9888
4th, Ditto	6·579	8th, Clyde Ironworks .	7·0028

"The specific gravity of the Muirkirk iron is considerably less than of that smelted at Carron and the Clyde Ironworks ; the mean of the eight specimens is 6·7034.

"It has been hitherto supposed that the difference between cast-iron and malleable iron consists in the presence of carbon in the former and its absence from the latter ; in other words, that cast-iron is a carburet of iron. But in all the specimens of cast-iron which we analysed we constantly found several other ingredients besides iron and carbon. Manganese is pretty generally present in minute quantity, though in one specimen it amounted to no less a quantity than 7 per cent ; its average amount is 2 per cent. *Silicon* is never wanting, though its amount is exceedingly variable ; the average quantity is about 1⅕ per cent ; some specimens contained 3⅕ per cent of it, while others contain less than a half per cent. Aluminum is very rarely altogether absent, though its amount is more variable than that of silicon. Its average amount is 2 per cent ; sometimes it exceeds 4½ per cent, and sometimes it is not quite 1-5000th part of the weight of the iron.

"Calcium and magnesium are sometimes present, but very rarely, and the quantity does not much exceed 1-5th per cent. In a specimen of cast-iron which I got from Mr. Neilson, and which he had smelted from pyrites, there was a trace of

copper, showing that the pyrites employed was not quite free from copper; and in a specimen from the Clyde Ironworks there was a trace of sulphur. The following table exhibits the composition of six different specimens of cast-iron No. 1, analysed in my laboratory either by myself or by Mr. John Tennent:—

	Muir-kirk.	Muir-kirk.	Muir-kirk.	Pyrites.	Carron.	Clyde.	Mean.
Iron . .	90·98	90·29	91·38	89·442	94·010	90·824	91·154
Copper .	...	...	...	0·288	...	...	...
Manganese .	...	7·14	2·00	...	0·626	2·458	2·037
Sulphur .	...	...	...	...	...	0·045	...
Carbon . .	7·40	1·706	4·88	3·600	3·086	2·458	3·855
Silica . .	0·46	0·830	1·10	2·220	1·006	0·450	1·177
Aluminum .	0·48	0·016	...	3·776	1·032	4·602	1·651
Calcium .	...	0·018	0·20	...	...	...	...
Magnesium .	...	...	...	...	...	0·340	...

"The constant constituents of cold-blast cast-iron No. 1, are iron, manganese, carbon, silicon, and aluminum. The occasional constituents are copper, sulphur, calcium, and magnesium. These occur so rarely, and in such minute quantity, that we may overlook them altogether.

"The constant constituents occur in the following mean atomic proportions:—

22 atoms iron	. . . .	=77·00
½ atom manganese	. . . . .	= 1·75
4·36 atoms carbon	. . . .	= 3.27
1 atom silicon	. . . .	= 1·00
1⅛ aluminum	. . . .	= 1·40—84·42

"(2.) I examined only one specimen of cast-iron No. 2. It was an old specimen, said to have come from Sweden; but I have no evidence of the correctness of this statement. Its specific gravity was 7·1633 higher than any specimens of cold-blast iron No. 1. Its constituents were—

Iron	93·594
Manganese	0·708
Carbon	3·080
Silicon	1·262
Aluminum	0·732
Sulphur	0·038—99·414

"The presence of sulphur in this specimen leads to the suspicion that it is not a Swedish specimen; for, as the Swedish ore is magnetic iron, and the fuel charcoal, the presence of sulphur in the iron is very unlikely.*

"In this specimen the atoms of iron and manganese are to those of carbon, silicon, and aluminum, in the proportion of 4½ to 1, instead of 3½ to 1, as in cast-iron No. 1.

"The atoms of carbon, silicon, and aluminum approach the proportions of 7, 2, and 1; so that in cast-iron No. 2, judging from one specimen, there is a greater proportion of carbon, compared with the silicon and aluminum, than in cast-iron No. 1.

"Mr. Tennent analysed a specimen of hot-blast iron No. 2 from Gartsherrie. Its specific gravity was 6·9156, and its constituents—

		Atoms.	
Iron	90·542 or	25·86	3·72
Manganese	2·764	0·78	
Carbon	3·094	4·05	1·
Silicon	0·680	0·68	
Aluminum	2·894	2·31	
Sulphur	0·023	0·011	
	99·997		

So that it resembles cast-iron No. 1 in the proportion of its constituents. The carbon is almost the same as in cold-blast iron No. 2; but the proportion of aluminum is four times as great, while the silicon is little more than half as much. The atomic ratios are—Carbon, 4; silicon, 0·67; aluminum, 2·28.

* I have been told by Mr. Mushet that the Swedes add sulphur to the iron No. 2.

"(3.) Five specimens of hot-blast cast-iron No. 1 were analysed. Two of these were from Carron and three from the Clyde Ironworks, where the hot-blast originally began, and where, of course, it has been longest in use. ' The specific gravity of these specimens was found to be as follows :—

1st, From Clyde Works	7·0028
2d, From Carron	7·0721
3d, From Carron	7·0721
4th, From Clyde Works	7·1022
Mean . .	7·0623

"It appears from this that the hot-blast increases the specific gravity of cast-iron by about 1-22d part. It approaches nearer the specific gravity of cast-iron No. 2, smelted by cold air, than to that of No. 1."

"The following table exhibits the constituents of these four specimens :—

	Clyde.	Carron.	Carron.	Clyde.	Clyde.
Iron . . .	97·096	95·422	96·09	94·966	94·345
Manganese . .	0·332	0·336	0·41	0·160	3·120
Carbon . . .	2·460	2·400	2·48	1·560	1·416
Silicon . . .	0·280	1·820	1·49	1·322	0·520
Aluminum . .	0·385	0·488	0·26	1·374	0·599
Magnesium . .	...	...	...	0·792	...
	100·553	100·466	100·73	100·174	100·000

"The mean of these analyses gives us—

		Atoms.	
Iron	95·584 or	27·31	6·5
Manganese	0·871	0·249	
Carbon	2·099	2·79	1·
Silicon	1·086	1·086	
Aluminum	0·422	0·337	
	101·285		

Or in the proportion of 6 atoms of iron and manganese to 1

atom of carbon, silicon, and aluminum. In the cold-blast cast-iron we have—

	Iron.	Carbon, etc.
In No. 1	$3\frac{1}{2}$ atoms	1 atom.
In No. 2	$4\frac{1}{2}$,,	1 ,,
In hot-blast	$6\frac{1}{2}$,,	1 ,,

"Thus, it appears that when iron is smelted by the hot-blast its specific gravity is increased, and it contains a greater proportion of iron, and a smaller proportion of carbon, silicon, and aluminum, than when smelted by the cold-blast."

The effects of the addition of different chemical substances produces a very peculiar effect on cast-iron, and tends very considerably to alter its mechanical properties. For example, the addition of phosphorus imparts to iron the property of fusing tranquilly and forming a thin liquid; and should the proportion exceed 1·5 per cent, it becomes very considerably deteriorated in quality. Arsenic, it is thought, improves the quality of iron; in fact, it is stated that the celebrated Low-moor iron owes its qualities to the arsenic it contains. The presence of sulphur is very injurious to cast-iron, causing numerous cavities and air-bubbles to be formed in the process of cooling. In the experiments at Shoeburyness we found the presence of only 0·37 per cent of sulphur caused brittleness in the armour-plates, as already observed.

As the means for opening up a new field of observation in connection with the strength of cast-iron, we may quote some of the general results from a very extensive series of analyses made by order of the United States Government. These analyses appear to have been made with extreme care, and the results, so far as they go, are satisfactory, and point to an explanation of some at least of the variations in the resisting powers of this material. We may premise that the guns of the United States Ordnance department are divided into three classes, according to the tests they have stood and the strength of the metal. A large number of specimens having been taken from

guns of each class, were submitted to analysis by Mr. Campbell Morfit and Mr. J. C. Booth, and gave the following remarkably consistent average results :—

	Specific gravity.	Tensile strength.	Total carbon.	Combined carbon.	Allotropic carbon.
First-class guns	7·204	28,805	·0384	·0178	·0206
Second-class guns	7·154	24,767	·0376	·0146	·0230
Third-class guns	7·087	20,148	·0365	·0082	·0283

The different effects produced by the *hot* and *cold* blast are clearly exhibited in the following table, both in reference to chemical composition and to specific gravity and tensile strength :—

Blast.	Specific gravity.	Tensile strength.	Total carbon.	Allotropic carbon.	Combined carbon.	Silicium.	Silicium and combined carbon.	Silicium and total carbon.	Slag.	Slag and allotropic carbon.
Hot	7·065	19,640	·0369	·0292	·0076	·0159	·0235	·0528	·00487	·0341
Cold	7·218	29,219	·0407	·0209	·0208	·0059	·0267	·0476	·00124	·0221

It will be observed that, while there is a very great disproportion in the quantities of each *single* ingredient in the hot and cold blast metal, yet there is nearly the same amount of several combined, such as the slag and allotropic carbon, the amount of silicium and combined carbon, or silicium and total carbon. These numbers are significant; for although there is not a great disparity between the amounts of total carbon produced by hot and cold blast, yet the hot-blast has evidently driven off a portion of carbon from combination, so that the cold-blast contains two and three-fourth times as much combined carbon. The hot-blast metal, however, meets with some compensation for this loss of carbon by reducing by its intense heat a larger amount of silica, and assuming silicium.

The wide difference in the amounts of slag in the two metals is also remarkable.

The slag and allotropic (graphitic) carbon being of a brittle nature, and not united with the iron, coat the crystalline plates of the metal, and diminish their surface of contact; and consequently it follows that the tensile strength of the metal must decrease partly in proportion to the increase of slag and allotropic carbon.

CHAPTER XIII.

THE STATISTICS OF THE IRON TRADE.

THIS work has already extended so much beyond the limits of our inquiry, that we must confine ourselves to an exceedingly brief notice of the statistics of this important manufacture. In 1740 the iron trade suffered a sudden check from a falling-off in the supply of charcoal, coal or coke not having been employed at that time for smelting. The annual production seems to have decreased from 180,000 to about 17,350 tons per annum. This comparatively small quantity was smelted in the following counties, viz.—

	Furnaces.	Tons.		Furnaces.	Tons.
Brecon	2	600	Nottingham	1	200
Glamorgan	2	400	Salop	6	2000
Carmarthen	1	100	Stafford	2	1000
Cheshire	3	1700	Worcester	2	700
Denbigh	2	550	Sussex	10	1400
Gloucester	6	2850	Warwick	2	700
Hereford	3	1350	York	6	1400
Hampshire	1	200	Derby	4	800
Kent	4	400			
Monmouth	2	900		59	17,350

	Tons	cwt.	qrs.
Annual average for each furnace	294	1	1
Weekly " "		13	0

Soon afterwards the difficulties in the way of using coal were overcome, and the manufacture extended rapidly. The number of charcoal furnaces decreased, but the quantity produced by each was considerably increased. The following table shows the state of the trade in 1788 :—

	Charcoal.			Coke.		
	Furnaces.	Tons each.	Total.	Furnaces.	Tons each.	Total.
Gloucester	4	650	2600	...	...	...
Monmouth	3	700	2100	...	...	...
Glamorgan	3	600	1800	6	1100	6,600
Carmarthen	1	400	400	...	...	...
Merioneth	1	400	400	...	...	...
Shropshire	3	600	1800	21	1100	23,100
Derby	1	300	300	7	600	4,200
York	1	600	600	6	750	4,500
Westmoreland . . .	1	400	400	...	...	...
Cumberland . . .	1	300	300	1	700	700
Lancashire	3	700	2100	...	...	...
Sussex	2	150	300	...	...	...
Stafford	...	...	...	6	750	4,500
Cheshire	...	...	...	1	600	600
Brecon	...	...	...	2	800	1,600
Stafford (about to blow)	...	...	...	3	800	2,400
	24	...	13,100	53	...	48,200

	Charcoal.			*Coke.*		
	Tons.	cwt.	qrs.	Tons.	cwt.	qrs.
Annual average from each furnace .	545	16	2	907	0	0
Weekly " " .	10	9	3	17	9	0

In the same year were erected and blowing in Scotland the following furnaces :—

	Charcoal.			Coke.		
	Furnaces.	Tons each.	Total.	Furnaces.	Tons each.	Total.
Goatfield . . .	1	700	700	...	...	...
Bunawe . . .	1	700	700	...	...	...
Carron . . .	...	...	...	4	1000	4000
Wilsontown . .	...	...	...	2	800	1600
	2	...	1400	6	...	5600

Total quantity of charcoal in Britain in 1788 .	14,500
Do. coke do. do. .	53,800
Total quantity of iron in Britain in 1788 .	68,300
Do. do. 1740 .	17,350
Increased produce of pig-iron . .	50,950

About the year 1796 it was contemplated by Mr. Pitt to add to the revenue by a tax on coal. This met with a powerful opposition on the part of the manufacturers and consumers, especially those in the iron trade. A committee was appointed, witnesses were examined, and the measure abandoned as unwise and impracticable. The following table exhibits an abstract of the facts collected, and shows the rapid progress of the iron trade in the eight preceding years :—

Counties.	No. of Furnaces.	Excise Return of Iron made.	Supposed quantity by the Trade.	Actual Return.
Chester	2	4,710	2,200	1,958½
Cumberland . . .	4	5,144	3,000	2,034
Derby	3	2,238	2,138	2,107
Gloucester . . .	2	380	380	380
Hereford	5	2,850	2,850	2,529
York	22	21,984	21,987	17,947
Shropshire . . .	23	68,129	43,360	32,969
Wales	28	45,994	42,606	35,485
Stafford	14	15,820	15,256	13,210
Sussex	1	172¾	173	173½
	104	167,321¾	133,950	108,793

	Tons.
The return from Scotland exhibited a list of 17 furnaces, and an exact return of pig-iron, manufactured, of	16,086
Making an annual total of	124,879
Annual average produce from each furnace, including charcoal furnaces	1,032
Increase of annual average since 1788 . . .	232

The following table shows the comparative make of pig-iron in 1820 and 1827 :—

	1820. Tons.	Furnaces.	1827. Tons.
North Wales	150,000	12	24,000
South Wales		90	272,000
Shropshire	180,000	31	78,000
Staffordshire		95	216,000
Yorkshire	50,000	24	43,000
Derbyshire		14	20,500
Scotland . .	20,000	18	36,000
	400,000	284	690,500

From that time to the present the manufacture has steadily increased. The following tables give the state of the trade in 1854-57: the particulars are extracted from the Mining Records, published under the direction of Mr. R. Hunt, in conection with the Museum of Practical Geology, London. The importance which Scotland has assumed in reference to the iron manufacture is especially worthy of notice.

Counties.	No. of Works.	No. of Furnaces erected.	No. of Furnaces in blast.	Total Produce in tons.
ENGLAND :—				
Northumberland, Durham, and Yorkshire	37	106	80	348,444
Derbyshire	13	33	25	127,500
Lancashire and Cumberland .	2	5	3	20,000
Staffordshire	72	203	166	247,600
Shropshire	13	34	28	124,800
Gloucestershire . . .	4	7	5	21,990
WALES :—				
Flintshire, Denbighshire . .	7	11	9	32,900
Glamorganshire, anthracite district	14	35	21	750,000
Glamorganshire and Monmouthshire, bituminous district .	34	134	100	
SCOTLAND :—				
Ayrshire	9	41	30	249,600
Lanarkshire	13	88	72	468,000
Other counties . . .	10	27	16	79,040
	228	724	555	3,069,874

Total Produce of Pig-Iron in Great Britain in 1857.

	Tons.
ENGLAND—	
Northumberland	63,250
Durham	284,500
Yorkshire	296,838
Lancashire	1,233
Cumberland	30,515
Derbyshire	112,160
Shropshire	117,141
North Staffordshire	134,057
South Staffordshire and Worcestershire . .	657,295

	Tons.
ENGLAND, *continued*—	
Northamptonshire	11,500
Gloucestershire	23,882
Somersetshire	300
WALES, North	37,049
„ South, anthracite districts . . .	63,440
„ South, bituminous districts . . .	907,287
SCOTLAND	918,000
IRELAND	1,000
Total produce in Great Britain and Ireland	3,659,447

The quantity of iron ore raised in all parts of the United Kingdom in 1857, and used in the production of pig-iron, was found from the same returns to be 9,573,281 tons.

For smelting which there were in active operation in

England . . .	333	blast-furnaces.
Wales . . .	170	„
Scotland . . .	124	„
Ireland . . .	1	„
	628	

The mean average price of the pig-iron "mixed numbers," deduced from all the sales of the year, was £3 : 10 : 2, which gives the market value of the pig-iron made as £12,838,560 per annum. If we assume that the make of iron has increased in the same rate since 1857, it must now amount to 4,250,000 tons.

In connection with the above, we insert the following table from Mr. Kenyon Blackwell's paper on the Iron Industry of Great Britain, read before the Society of Arts. It gives the estimated production of crude iron in the various countries.

	Tons.		Tons.
Great Britain . .	3,000,000	Russia . . .	200,000
France . . .	750,000	Sweden . . .	150,000
United States . .	750,000	Various German States	100,000
Prussia . . .	300,000	Other countries .	300,000
Austria . . .	250,000		
Belgium . . .	200,000		6,000,000

The following table gives the annual production of steel in various countries :—

England—Cast-steel	23,000	tons.
Bar-steel	7,000	„
Spring-steel	10,000	„
Total	40,000	„
France	15,000	„
Prussia	5,453	„
Austria	13,037	„
United States	10,000	„

In referring to the above, it will be seen that Great Britain produces as much crude iron as all other countries put together ; and a great portion of that iron being converted into bars and plates, indicates a large and important article of production,—an article of immense value to the country—of great demand at home and abroad—and justly entitled, not only to improvements and economy in its manufacture, but to the generous support of a liberal and an enlightened Government.

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